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AGING AND SURVEILLANCE TESTING OF A MINUTEMAN LGM-30F STAGE II ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE (MOTOR S/N AA20078, DESIGNATION OP-15)

F. D. Cantrell and J. D. Gibson

ARO, Inc.

February 1973

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ENGINE TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

AGING AND SURVEILLANCE TESTING OF A MINUTEMAN LGM-30F STAGE II ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE (MOTOR S/N AA20078, DESIGNATION OP-15)

F. D. Cantrell and J. D. Gibson
ARO, Inc.

FOREWORD

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC) at the request of the Space and Missile Systems Organization (SAMSO), Air Force Systems Command (AFSC), under Program Element 11213F, System 133B.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted on December 12, 1972, under ARO Project No. RA254. The manuscript was submitted for publication on January 12, 1973.

This technical report has been reviewed and is approved.

CHAUNCEY D. SMITH, JR. Lt Colonel, USAF Chief Air Force Test Director, ETF Directorate of Test	A. L. COAPMAN Colonel, USAF Director of Test

ABSTRACT

LGM-30F Stage II solid-propellant rocket motor, designated OP-15, was fired on December 12, 1972, in Rocket Development Test Cell (J-5), Engine Test Facility (ETF), in support of the operational phase of the Minuteman Aging and Surveillance test program. The objective of this test was to determine any degradation in performance or decrease in reliability that may have occurred as a result of 7.3 years of operational deployment. Motor ballistic performance was within specification. The motor was ignited at a pressure altitude of 98,000 ft. Motor ignition delay time was 109 msec. Motor action time was 65.82 sec, during which the motor produced an unaugmented vacuum total impulse of 3,951,955 lbf-sec. The unaugmented vacuum specific impulse was 287.61 lbf-sec/lbm. Average chamber pressure during motor action time was 456 psia. The liquid-injection thrust vector control and roll control systems operated satisfactorily throughout the firing. Postfire motor structural integrity was satisfactory. Data are presented showing the performance of this motor as compared to the performance of other LGM-30F Stage II motors tested at AEDC.

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APPENDIXES

SECTION I
INTRODUCTION

The purpose of the Minuteman Aging and Surveillance (A&S) Program (Ref. 1) is to obtain data for use in predicting the service life of the propulsion subsystem of the Minuteman Weapons System. The full-scale Minuteman LGM-30F Stage II rocket motor Aging and Surveillance Program consists of two phases, a research and development phase and an operational phase. As part of the operational motor phase of the program, the results of firing a number of full-scale motors which have been operationally deployed are to be analyzed. Fourteen motors in this program have already been fired at AEDC. The test reported herein was conducted with the fifteenth of the operational surveillance motors which are scheduled for firing at AEDC. The specific objectives of the operational phase of the Aging and Surveillance Program for the LGM-30F Stage II motors are to:

1. Determine that operational motors will perform within model specification limits (Ref. 2) and

2. Provide ballistic data on operational motors to aid in estimating shelf/service life of second-stage motors.

At the time of firing, this motor was 7.3 yr old. Ballistic and auxiliary systems performance data obtained during this test are compared with data obtained from previous firings of LGM-30F Stage II motors at AEDC.

SECTION II
APPARATUS

2.1 TEST ARTICLE DESCRIPTION

The primary components of the LGM-30F Stage II solid-propellant rocket motor (Fig. 1, Appendix I) are a cylindrical titanium alloy chamber loaded with ANB-3066 propellant; a single, partially submerged nozzle and nozzle extension (Fig. 2) which provides an overall expansion ratio of 24.8; and a propellant-type igniter with a safe-and-arm device. Mounted on the aft end of the chamber surrounding the nozzle are a secondary liquid-injection thrust vector control (LITVC) system and a hot gas roll control (RC) system. A summary of test article configuration information is presented in Table I (Appendix II).

Nominal length of the LGM-30F Stage II motor is 162 in.; nominal motor case diameter is 52 in. The maximum gross weight of the motor is approximately 15,600 lbm of which about 13,700 lbm is propellant.

The LITVC system is designed to impose pitch and yaw forces on the missile by injecting a secondary fluid into the exhaust gas stream at an area ratio of 8.36 (21.8 in. downstream of the nozzle throat). At each of the four injection points, a servocontrolled hydraulically actuated valve (Fig. 3) with three pintles is used to control injectant flow rate. The injectant fluid, Freon® 114B2, is supplied to the four injector valves through separate supply lines connected to a toroidal storage and expulsion tank (Fig. 4) located on the aft end of the chamber. For this test, only three valves were used. A steel plate was installed in place of Valve No. 3 (180-deg location) which blocked the injectant ports to the nozzle as well as the Freon 114B2 supply. The pressurization gas is provided by a solid-propellant gas generator. System pressure is controlled by a preset, spring-operated, poppet-type relief valve which dumps the unused gas overboard through two diametrically opposed ports located on the motor aft skirt.

The motor has an additional solid-propellant gas generator which exhausts tangentially through two pairs of nozzles in the motor aft skirt (Fig. 5) to provide roll control. The two control valves provide equal gas flow through opposing nozzles during null periods. When a roll moment is required, flow through the appropriate nozzle in each pair is restricted by closing the valve poppet producing the required moment.

2.2 PREFIRE HISTORY

The chamber used on Motor OP-15 was manufactured by Aerojet Downey and the chamber liner was applied on August 23, 1965. The propellant was cast on August 26, 1965, and cure was completed on September 7, 1965. Radiographic inspection of the propellant grain was conducted at Aerojet-Sacramento on September 21, 1965. The grain did conform to Aerojet Specification 32121B.

The motor was deployed and was recycled from Missile 65-341 at Grand Forks AFB on August 3, 1970. In August 1972, the motor was assigned to the A&S Program.

2.3 TEST CELL AND INSTALLATION

Rocket Development Test Cell (J-5) (Fig. 6 and Ref. 3) is a horizontal complex for testing rocket motors with up to 100,000-lbf thrust at pressure altitudes of approximately 100,000 ft. The cell is 16 ft in diameter and 50 ft long.

The cell is equipped with a temperature-conditioning system to maintain the test cell and motor at a prescribed temperature range from motor installation until prefire pumpdown.

The multicomponent thrust stand utilized (Fig. 7) is capable of measuring axial forces of 100,000 lbf and yaw forces of 6,000 lbf. The thrust stand natural frequency for the fully loaded LGM-30F Stage II motor is approximately 25 Hz in the axial direction and 20 Hz in the yaw direction. A steam ejector-diffuser system is used in conjunction with rotating exhauster machinery to provide altitude simulation. An auxiliary steam ejector pumping system is also used to remove roll control and overboard dump gases from the test cell.

2.4 INSTRUMENTATION

The types of data acquisition and recording systems used during this test were a multiple-input digital data acquisition system scanning each parameter at a basic rate of 200 samples/sec and recording on magnetic tape; frequency modulation (FM) systems recording on magnetic tape; photographically recording galvanometer-type oscillographs recording at paper speeds of 16 and 40 in./sec; and direct inking, null-balance potentiometer-type strip charts. Photo-optical recorders provided a permanent visual record of the firing. Table II presents a summary of motor instrumentation. Instrumentation calibration techniques are described in Appendix III. Uncertainties of the J-5 instrument systems are presented in Appendix IV.

SECTION III
PROCEDURE

The motor arrived at AEDC on November 6, 1972. Significant motor inspection and handling records are presented as follows:

Date	Activity or Item Performed	Remarks
November 6, 1972	Motor received at AEDC; visual inspection performed	No visible damage
November 10, 1972	Radiographic inspection completed	Met requirements of AGC Specification 32121B
November 13, 1972	Motor transferred to the Rocket Preparation Area	
November 15, 1972	Nozzle throat and exit plane diameter measurements taken	Results of exit plane measurements in Table III
November 16, 1972	Leak test, LITVC overboard dump system, per STM-161	Leak test satisfactory
November 16, 1972	Leak test, LITVC servoinjector valves, per STM-161	Leak test satisfactory
November 16, 1972	Leak test, RC system, per STM-161	Leak test satisfactory
November 16, 1972	Leak test, motor case, per STM-161	Leak test satisfactory

Date	Activity or Item Performed	Remarks
November 16, 1972	Leak test, LITVC gas generator manifold, per STM-161	Leak test satisfactory
November 16, 1972	Installation of transducers completed	
December 11, 1972	Motor transferred to test cell and installed	
December 11, 1972	Motor safe-and-arm, arm/disarm, and ignition systems check	Ignition systems verified
December 11, 1972	Electrical check, roll control valves, per STM-161	Electrical check satisfactory
December 11, 1972	LITVC servoinjector valves pintle calibrations	
December 12, 1972	Motor fired	
December 12, 1972	Visual inspection performed	Motor condition satisfactory Nozzle sea-level liner missing
December 12, 1972	Motor removed from test cell and transferred to Rocket Preparation Area	
December 13, 1972	Removed LITVC servoinjector valves from motor	Shipped to Hill AFB, Utah, for refurbishment
December 13, 1972	Nozzle throat and exit plane diameter measurements taken	Results in Table III
December 19, 1972	Motor shipped to Aerojet Solid Propulsion Company, Sacramento, California	

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

The results reported herein were obtained from firing an LGM-30F Stage II motor (S/N AA 20078, Designation OP-15) in Rocket Development Test Cell (J-5) on December 12, 1972, in accordance with Ref. 4. This was the fifteenth of a series of operational surveillance motors to be fired at AEDC as part of the operational motor phase of the Minuteman Aging and Surveillance Program. The motor was conditioned at 65 ± 5°F at AEDC in excess of 60 hours with the propellant grain temperature at ignition being 66°F. A summary of storage and conditioning temperature is presented in Table IV.

4.2 BALLISTIC PERFORMANCE

A summary of motor performance data is presented in Table V. Data from this test are compared with data obtained from other tests of LGM-30F Stage II motors fired at AEDC in Table VI. Plots of axial force, chamber pressure, and test cell pressure are presented in Fig. 8.

4.2.1 Motor Ignition

The motor was successfully ignited at a pressure attitude of 98,000 ft (0.175 psia) geometric pressure altitude, Z, Ref. 5. The motor ignition delay (defined as the time from application of ignition voltage until chamber pressure reaches 371 psia) was 109 msec. Chamber pressure during the ignition transient is presented in Fig. 10.

4.2.2 Action Time

Motor action time, defined as the time from the application of ignition voltage until the chamber pressure drops to 28 psia, was 65.82 sec. A plot of action time adjusted to 80°F versus age for motor OP-15 and other LGM-30F Stage II motors fired at AEDC is presented in Fig. 11.

4.2.3 Combustion Chamber Pressure

Average combustion chamber pressure during motor action time was 456 psia. The maximum operating chamber pressure occurred at T + 21.10 sec and was 530 psia, which was less than the 570-psia maximum limit in the model specification. Measured chamber pressure during motor operation is compared with manufacturer's predicted chamber pressure (Ref. 6) and the specification maximum limit in Fig. 12. Chamber pressure during motor tailoff is compared with the specification envelope in Fig. 13.

4.2.4 Axial Thrust and Thrust Coefficient

Vacuum-corrected thrust was within model specification limits for a motor temperature conditioned at 60 to 70°F and is presented with the manufacturer's predicted thrust (Ref. 6) and the specification envelope in Fig. 14. Average vacuum-corrected unaugmented thrust during motor action time was 60,042 lbf, which was within the 53,900-lbf minimum and 64,000-lbf maximum prescribed. Vacuum thrust during motor tailoff remained within its specification envelope as seen in Fig. 15. The average vacuum-corrected thrust for this motor is compared with other LGM-30F Stage II motors fired at AEDC in Fig. 16.

The average thrust coefficient during motor action time, excluding thrust augmentation, was calculated using the equation presented in Appendix V. The average unaugmented vacuum thrust coefficient calculated for this motor was 1.802.

4.2.5 Total Impulse

Measured total impulse during motor action time, including thrust augmentation, was 3,941,444 lbf-sec. Measured total impulse during motor action time, excluding thrust augmentation, was 3,933,457 lbf-sec and was obtained by the method presented in Appendix V. Total impulse corrected to vacuum conditions was obtained by adding the product of the cell pressure integral and prefire nozzle exit area to the measured total impulse. This vacuum correction was approximately 0.5 percent of the measured total impulse. The vacuum total impulse during action time, including thrust augmentation, was 3,959,942 lbf-sec. The vacuum total impulse during action time, excluding thrust augmentation, was 3,951,955 lbf-sec, which was greater than the 3,907,000-lbf-sec minimum requirement for this parameter from the model specification (Ref. 2). The vacuum total impulse during action time, excluding thrust augmentation for this motor, is compared with the other LGM-30F Stage II motors fired at AEDC in Fig. 17.

4.2.6 Vacuum Specific Impulse

Vacuum specific impulse was obtained by the method shown in Appendix V. Vacuum specific impulse for this motor was 287.61 lbf-sec/lbm. This specific impulse is compared with the specific impulse for the other LGM-30F Stage II motors fired at AEDC in Fig. 18. A plot of specific impulse versus motor age is presented in Fig. 19.

4.2.7 Motor Propellant Flow Rate

Average exhaust gas mass flow rate during action time was 208.8 lbm/sec. A plot of exhaust gas mass flow rate during motor operation is presented in Fig. 20. The flow rate calculation was performed utilizing the equation presented in Appendix V.

4.3 LIQUID-INJECTION THRUST VECTOR CONTROL AND ROLL CONTROL SYSTEMS PERFORMANCE

The LITVC and RC gas generators were successfully ignited as programmed, 3.7 sec before main motor ignition. Pressure altitude at the time of gas generator ignition was 106,000 ft (0.126 psia). Plots of RC and LITVC gas generator pressures over the period of their operation are presented in Fig. 21. The RC system performance is presented in Table V along with other performance parameters. The standard RC and LITVC duty cycles are described in Tables VII and VIII, respectively.

The maximum interval from LITVC gas generator ignition voltage application until the first indication of pressure in the injector cavities was 160 msec, which was within the specified maximum of 880 msec. The time from LITVC gas generator zero time until attainment of 500-psia Freon tank pressure was 320 msec, well within the 950-msec maximum defined in the model specification.

The LITVC servoinjector valves were calibrated with Freon 114B2 at the valve manufacturer's flow calibration facility before installation on the motor. Tabulations of these calibration values, together with the results from the pintle position transducer calibrations were used for reduction of the LITVC firing data at AEDC by the method presented in Appendix V.

Injector pintle position, injectant flow rate, and injector cavity pressure during the firing are presented in Figs. 22 through 24. The injector valve command voltages were satisfactorily programmed throughout the firing and the injector valves responded as programmed, producing the desired injectant flow rates. The Freon supply was depleted at T + 106.4 sec as indicated by the rapid decrease in Freon injectant pressure at that time. Bladder rupture did not occur on this firing. Freon tank and Freon manifold pressures are presented in Figs. 25 and 26, respectively. The pressure in the injector cavities is shown in Fig. 27 as a function of injectant flow rate. The maximum injector pressure reached was 649 psia at 1.06 sec after gas generator ignition (T - 2.64 sec).

The resultant yaw force during motor operating time (Fig. 28) indicates that thrust vectoring occurred as programmed. The average resultant yaw force recorded during the full-open secondary injection step (from T + 2 to T + 3 sec) was 4406 lbf, which exceeded the 3800-lbf minimum yaw force capability required during the period from T + 0.250 to T + 3 sec. An injectant flow rate of 58.0 lbm/sec was obtained during the full-open step. A thrust vector angle of 2.30 deg was produced during the period from T + 52 to T + 53 sec for an injectant flow rate of 26.8 lbm/sec, exceeding the minimum thrust vector angle capability (2.0 deg) required from T + 3 sec until the end of motor action time or depletion of injectant as set forth in the model specification (Ref. 2).

Liquid-injection thrust vector control performance values from this motor firing are plotted on composite plots of yaw-force injectant specific impulse, percentages of axial-thrust augmentation, yaw-to-axial force ratio, and axial-thrust augmentation injectant specific impulse versus injectant-to-motor flow rate for other LGM-30F Stage II motors tested at AEDC in Figs. 29 through 32. The values obtained during this test (summarized in Table IX) compare favorably with the results of the previous LGM-30F Stage II tests.

4.4 MOTOR THERMAL DATA

Motor case temperatures did not exceed the maximum limits delineated in the model specifications during motor action time. Thermocouple locations are presented in Fig. 33. Table X contains a summary of temperature increases during action time for all operational motors fired at AEDC in addition to this motor.

4.5 MOTOR STRUCTURAL INTEGRITY

The water quench was initiated at T + 68 sec. Visual postfire inspection revealed the motor to be in satisfactory condition (Fig. 34). However, the nozzle sea-level liner had been ejected during the firing at T + 65.1 sec. Postfire nozzle throat and exit plane diameter measurements were taken and are presented in Table III.

Figure 34c shows the posttest internal insulation condition at 0 degrees and approximately 43 inches aft of the igniter boss. This photograph was requested by SAMSO since bubbling of the internal insulation had occurred on two previous motors tested at AEDC. No bubbling in the insulation is noticeable for this motor.

SECTION V
SUMMARY OF RESULTS

The results of firing a 7.3-yr-old LGM-30F Stage II Aging and Surveillance motor (S/N AA 20078, Designation OP-15) at an average pressure altitude of 100,000 ft are summarized as follows:

1. All motor ballistic performance conformed to model specification requirements for the LGM-30F Stage II propulsion subsystem.

2. The motor was ignited at a simulated pressure altitude of 98,000 ft. The ignition delay was 109 msec, which was within the specification limit of 250 msec.

3. Vacuum-corrected total impulse was 3,951,955 lbf-sec (excluding augmentation), which exceeded the required minimum of 3,907,000 lbf-sec. Vacuum specific impulse was 287.61 lbf-sec/lbm.

4. The LITVC system operated satisfactorily and produced a resultant yaw force of 4406 lbf during the time period from 2 to 3 sec after main motor ignition, which was greater than the 3800-lbf minimum in the model

specifications. Likewise, during the period from T + 52 to T + 53 sec, a thrust vector angle of 2.30 deg was produced, exceeding the 2-deg minimum capability required in the model specification.

5. The RC system operated satisfactorily throughout the firing.

6. The nozzle sea-level liner was ejected at T + 65.1 sec.

7. The postfire structural condition of the motor was good.

REFERENCES

1. TRW Systems Group. "Minuteman Propulsion Master Surveillance Plan." 12128-0013-T0-00, July 31, 1969.

2. Aerojet-General Corporation. "Model Specification, Motor Rocket, SR19-AJ-1, Solid-Propellant Operation." S-133-1002-0-1, March 18, 1968.

3. Test Facilities Handbook (Ninth Edition). "Engine Test Facility, Vol. 2." Arnold Engineering Development Center, July 1971.

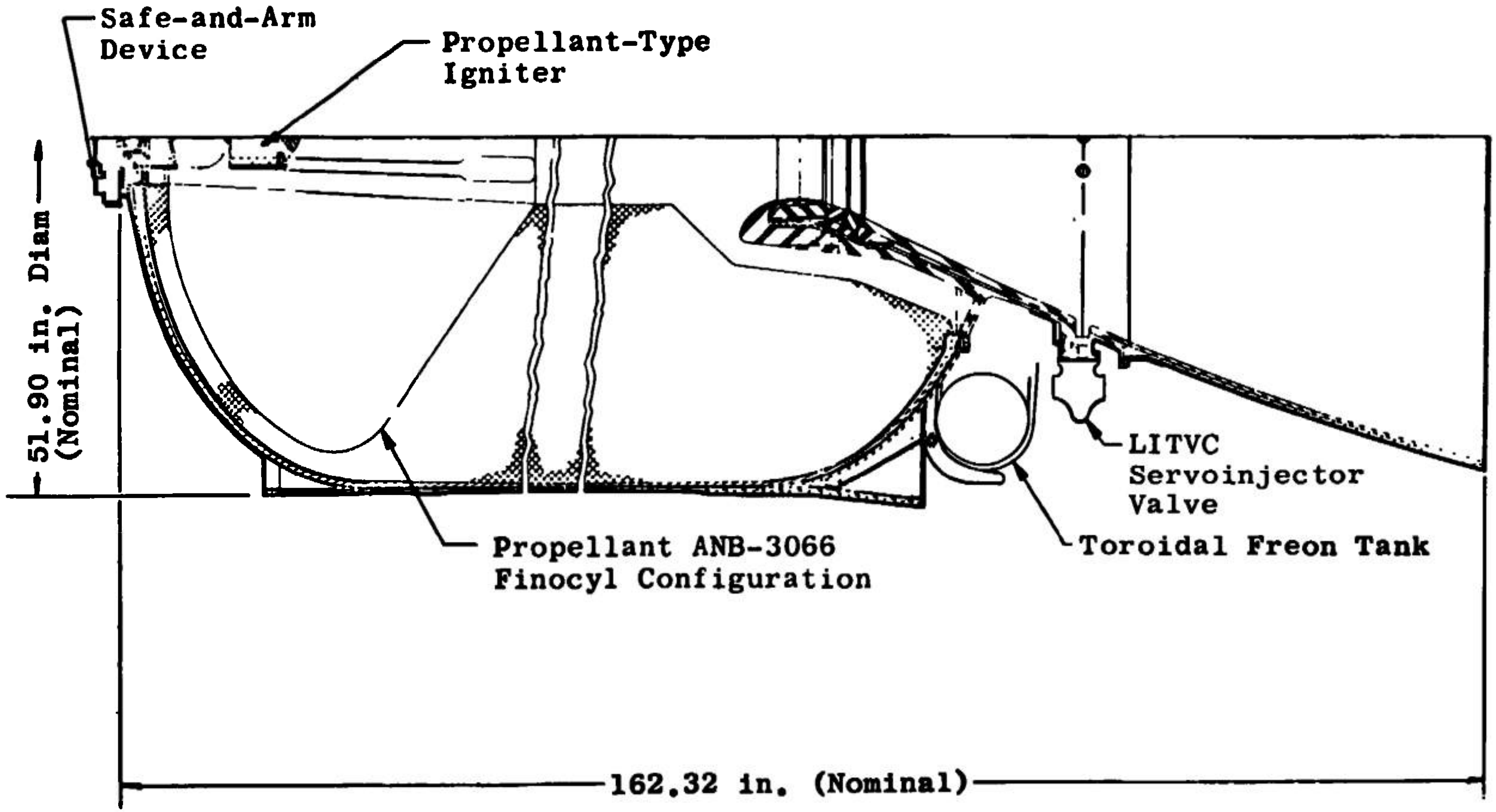
4. SAMSO. "Minuteman II LGM-30F Stage II Motor Surveillance Program Requirements." Minuteman Engineering Directive 70-13, Revision 1, April 1, 1971.

5. Dubin, M., Sissenwine, N., and Wexler, H. U.S. Standard Atmosphere, 1962. U.S. Government Printing Office, Washington, D.C., December 1962.

6. Aerojet-General Corporation. "Rocket Motor Assembly and Inspection Log Book, Rocket Motor SR-19-AJ-1, Designation OP-15." October 1965.

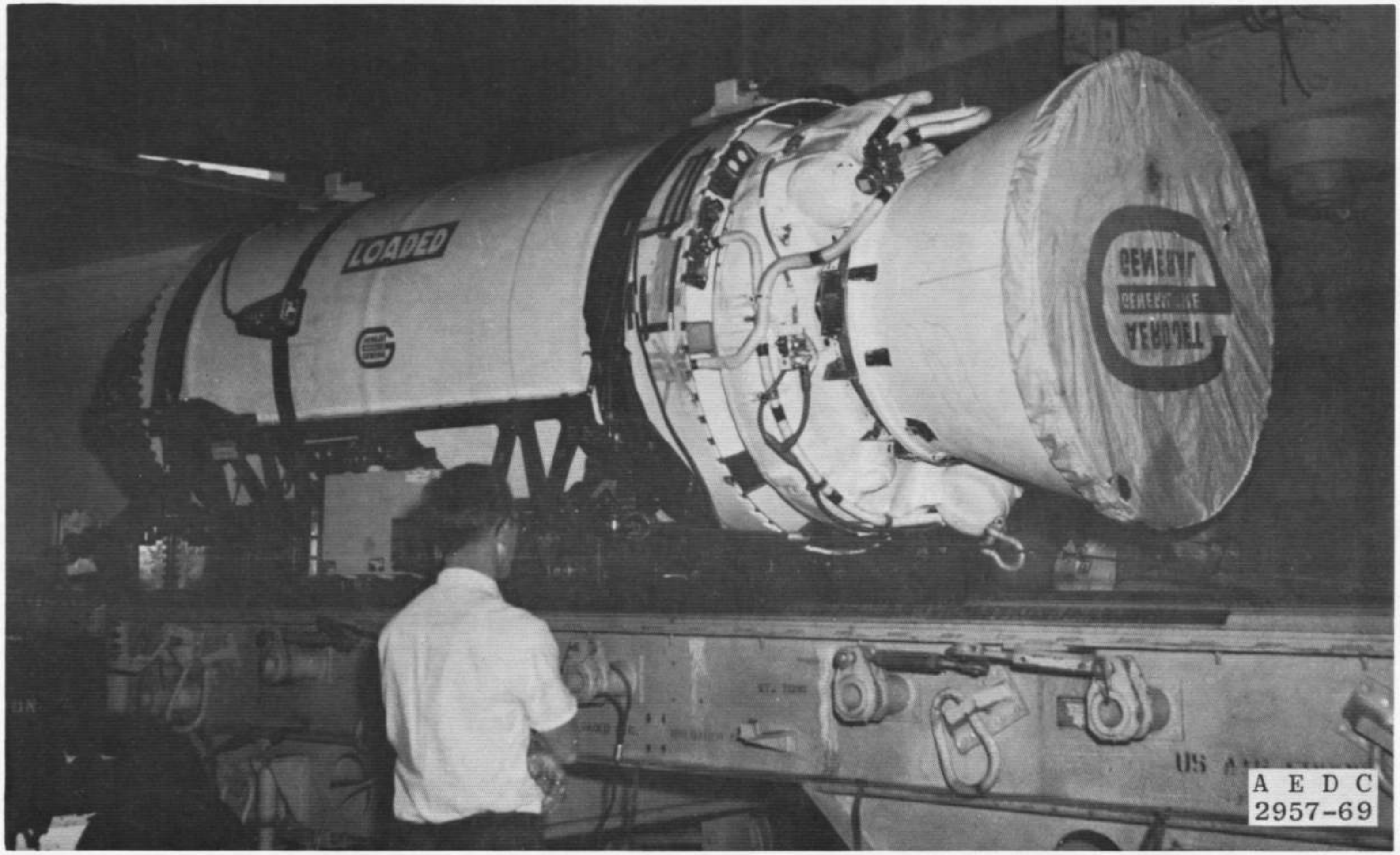
APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION CALIBRATIONS
IV. UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS
V. METHODS OF CALCULATION

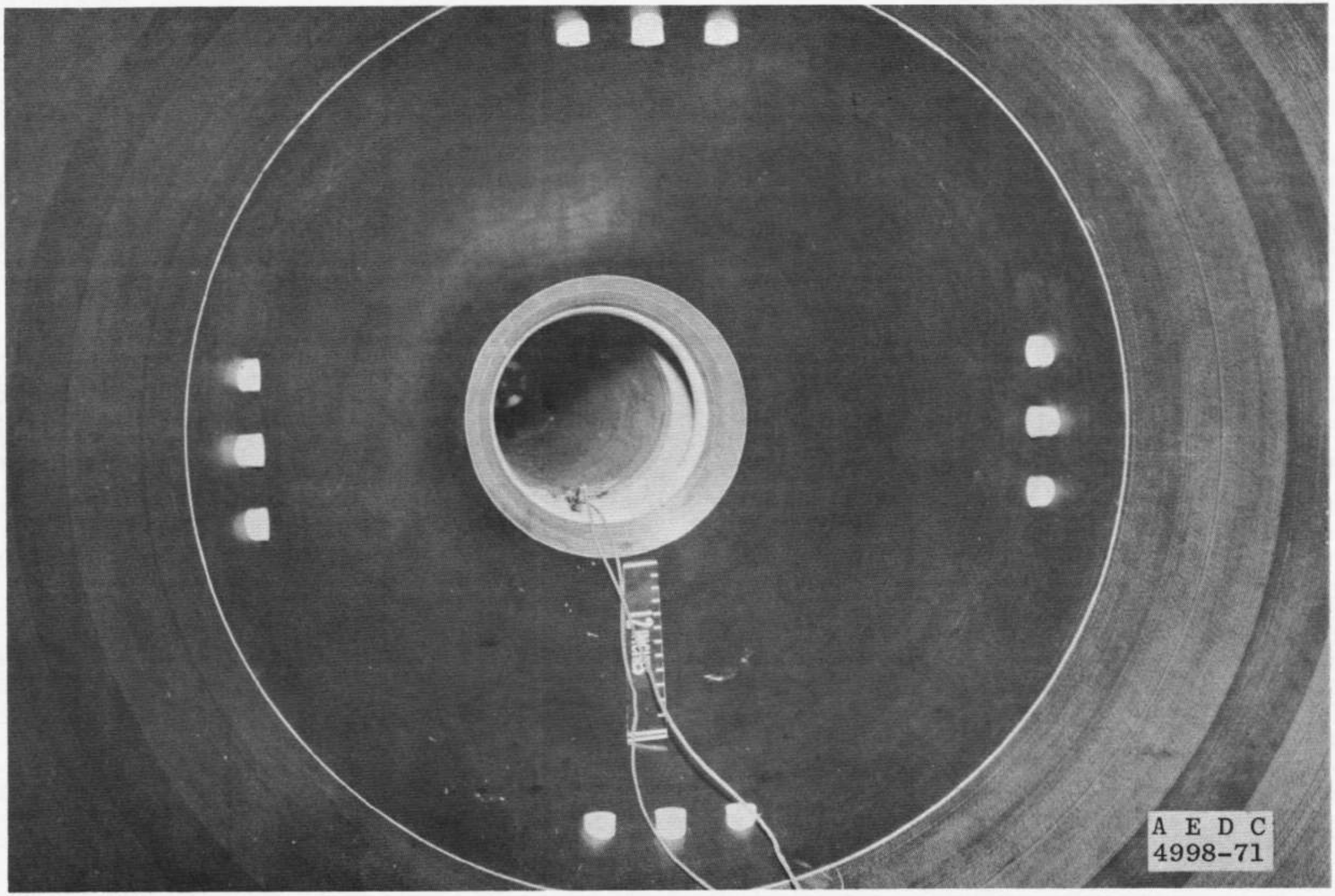


a. Quarter Section

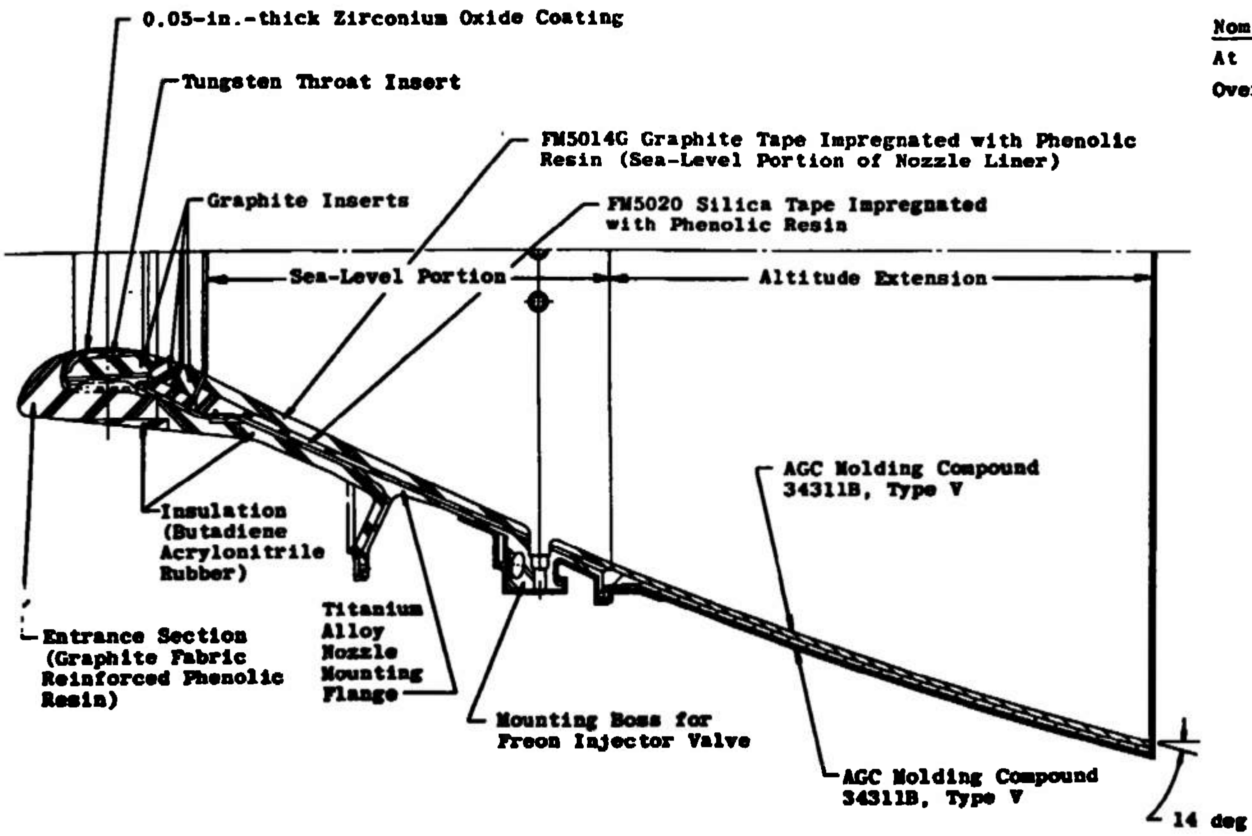
Fig. 1 Minuteman LGM-30F Stage II Motor



b. Overall View of Typical Motor
Fig. 1 Continued



c. Nozzle Prefire
Fig. 1 Concluded



Nominal Area Ratio (AE/AT)	
At Injection Plane	8.36
Overall	24.8

Length from Nozzle Throat, in.	Radius, in.
4.374	5.867
6.678	7.025
8.996	8.157
11.325	9.264
13.667	10.344
16.021	11.398
18.386	12.426
20.763	13.427
23.151	14.402
25.549	15.350
27.958	16.271
30.378	17.166
32.806	18.033
35.245	18.873
37.692	19.684
40.149	20.472
42.614	21.230
45.088	21.961
47.569	22.664
50.058	23.339
52.555	23.987

Fig. 2 Nozzle Assembly

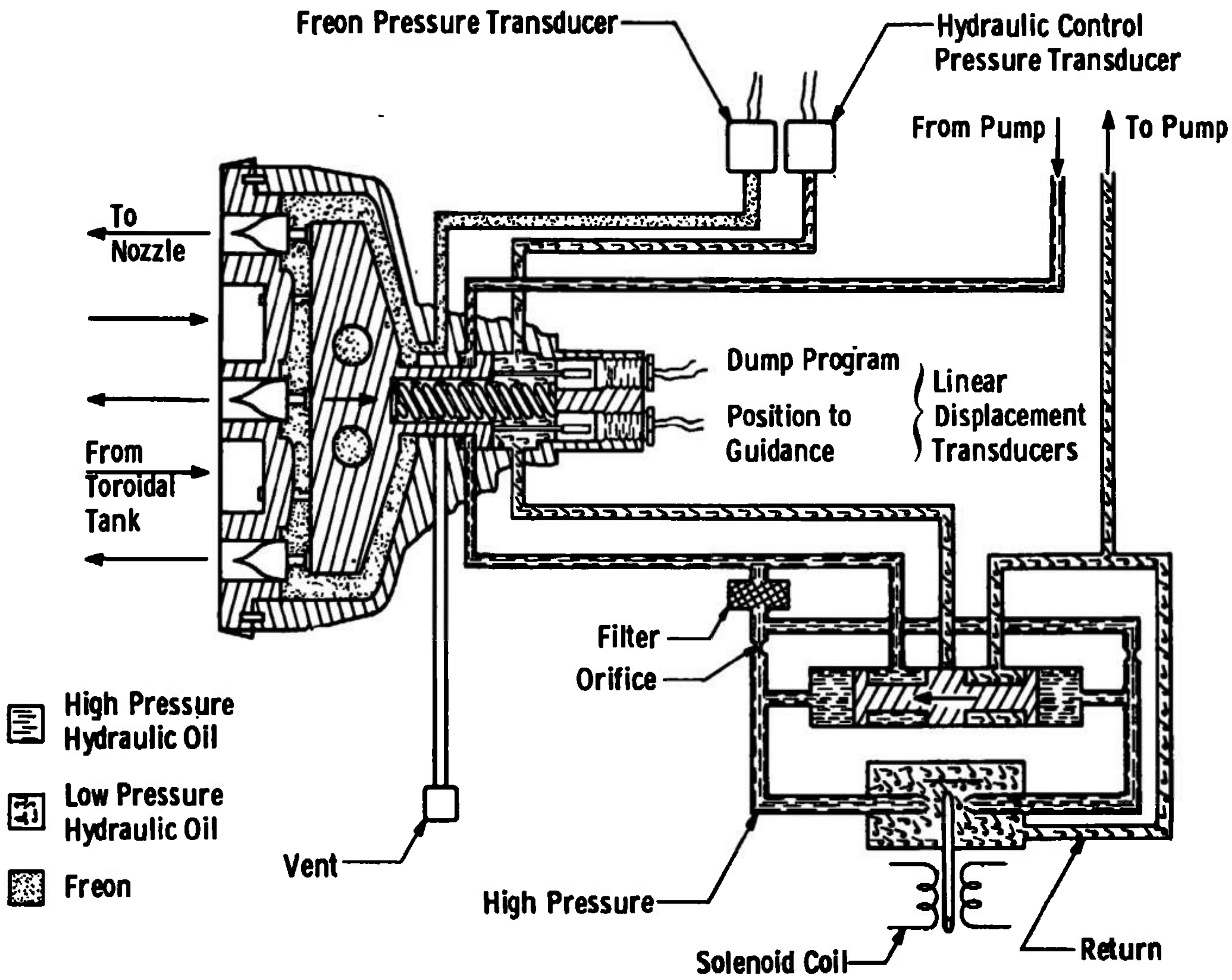


Fig. 3 Liquid-Injection Thrust Vector Control Injector Valve

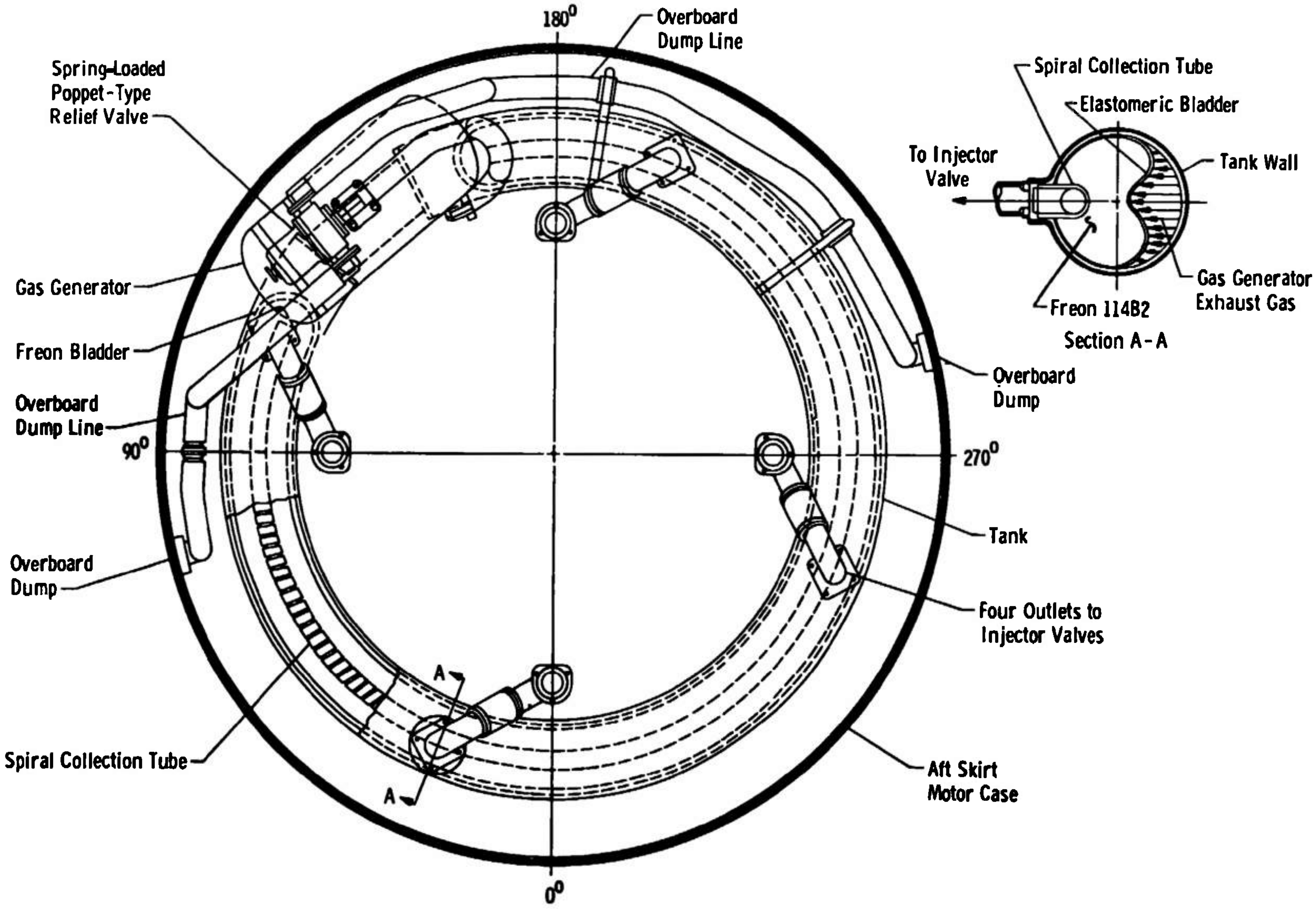


Fig. 4 Schematic of Liquid-Injection Thrust Vector Control System

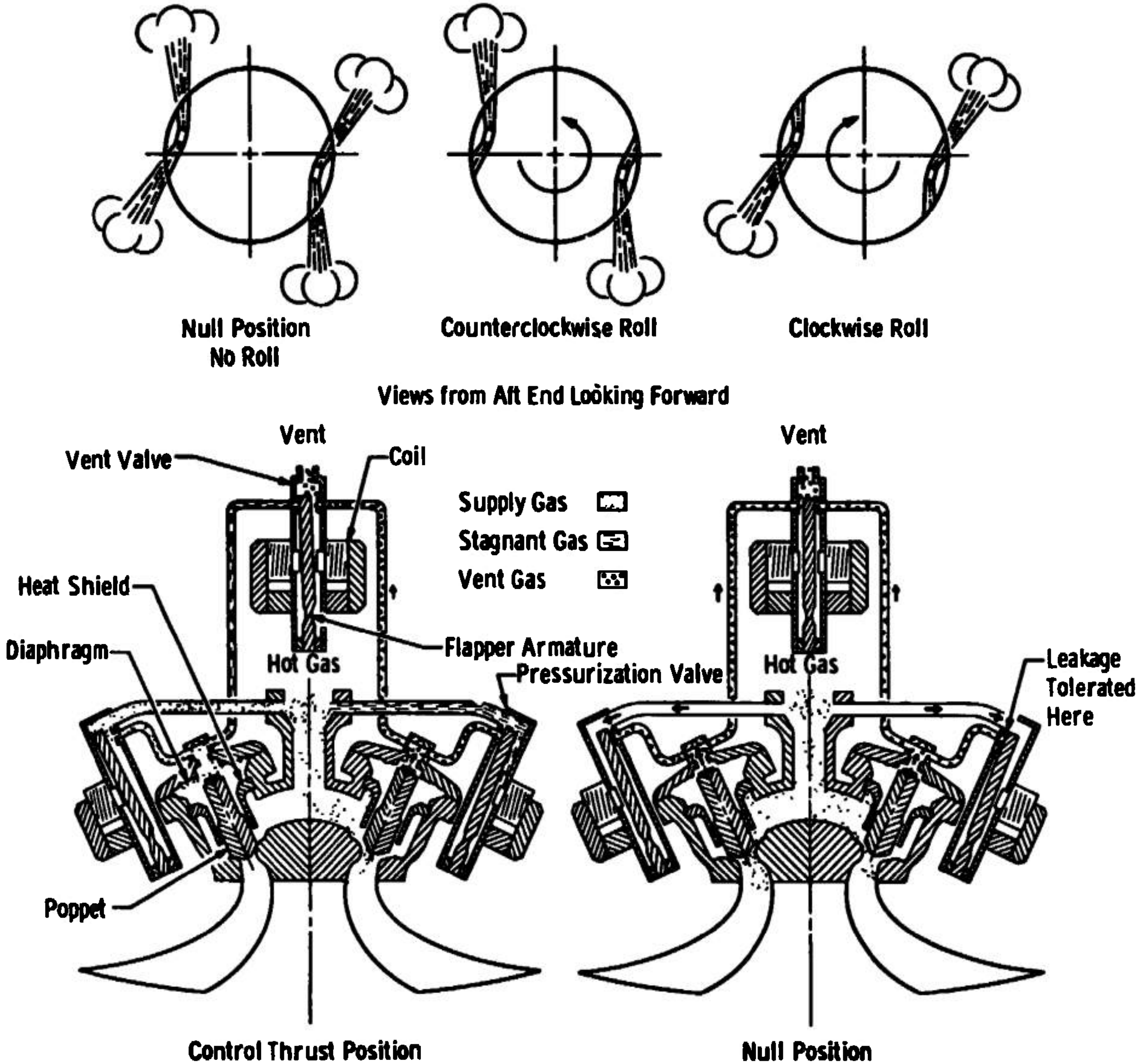


Fig. 5 Roll Control System

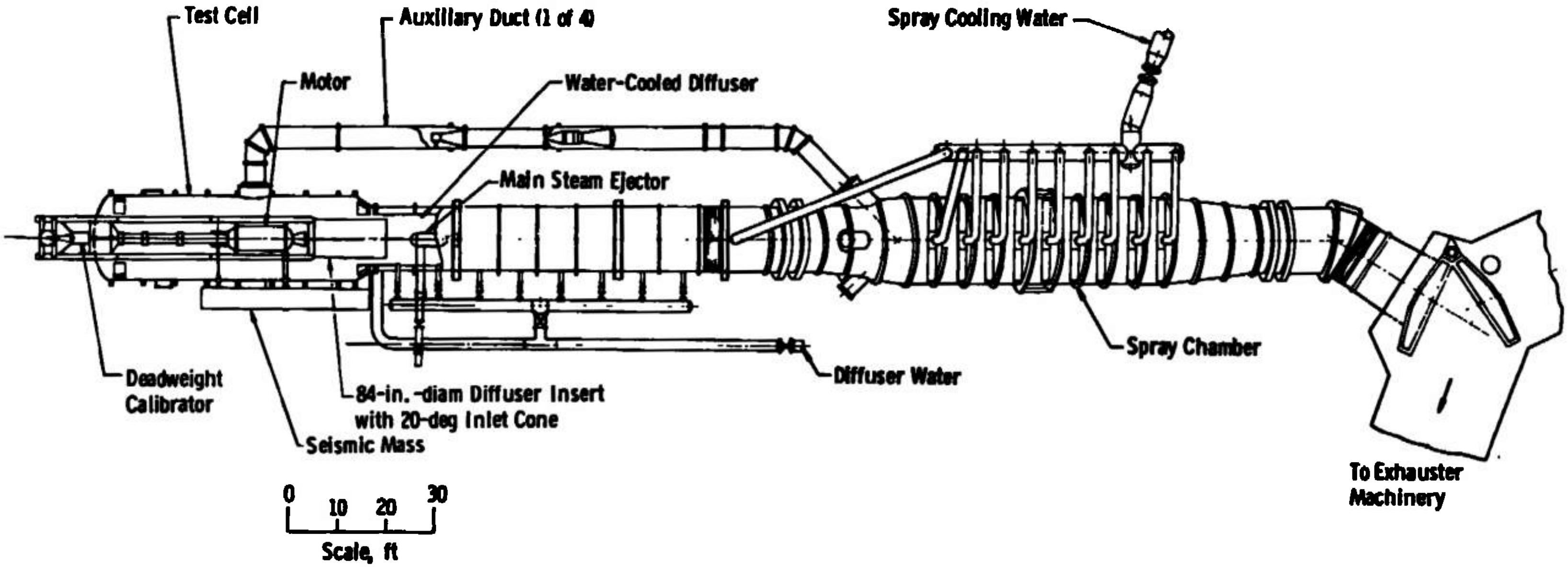


Fig. 6 Rocket Development Test Cell J-5

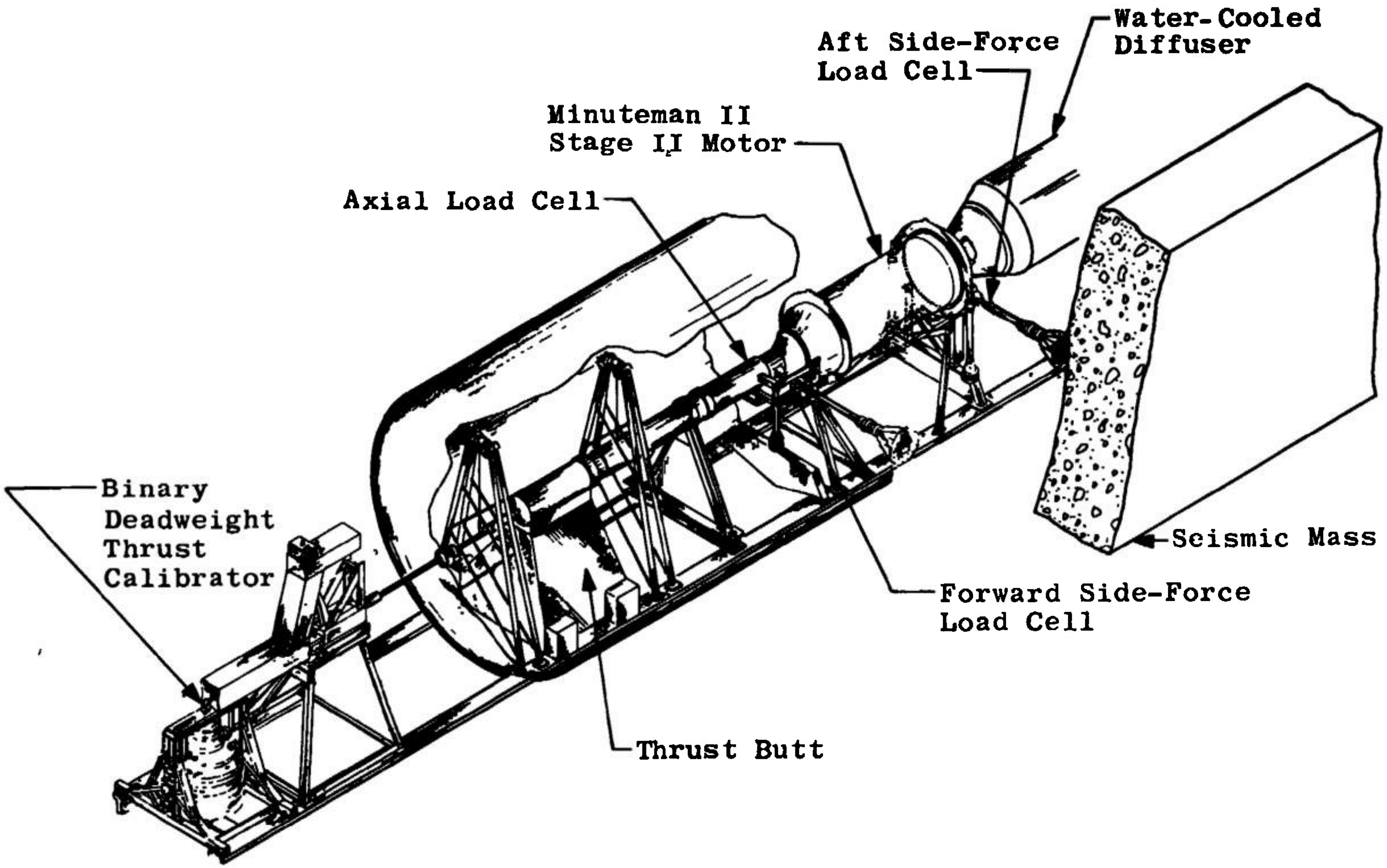


Fig. 7 Schematic of Thrust Stand

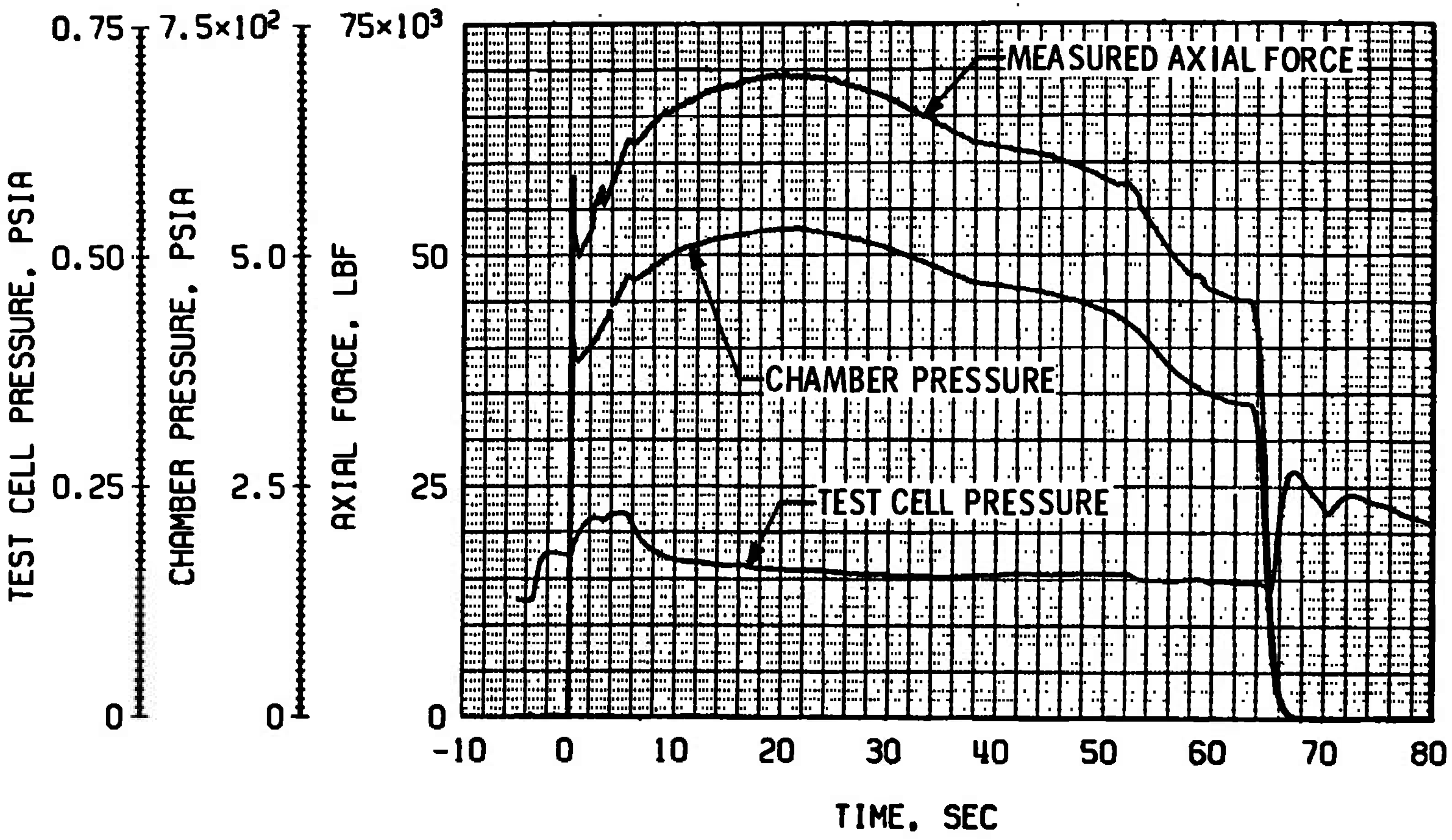


Fig. 8 Measured Axial Force, Chamber Pressure, and Test Cell Pressure during Motor Operation

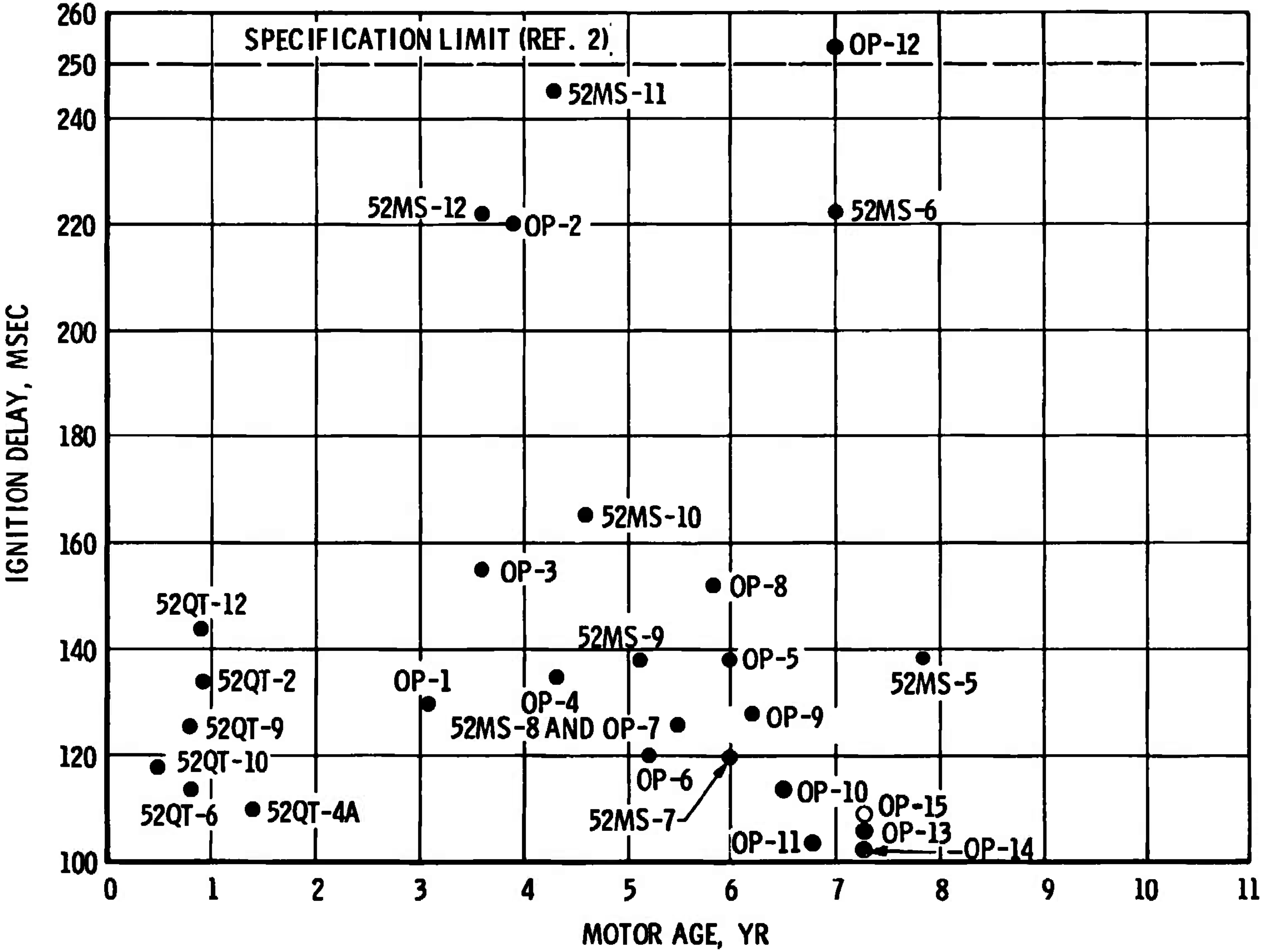


Fig. 9 Ignition Delay versus Age for Minuteman LGM-30F Stage II Motors Fired at AEDC

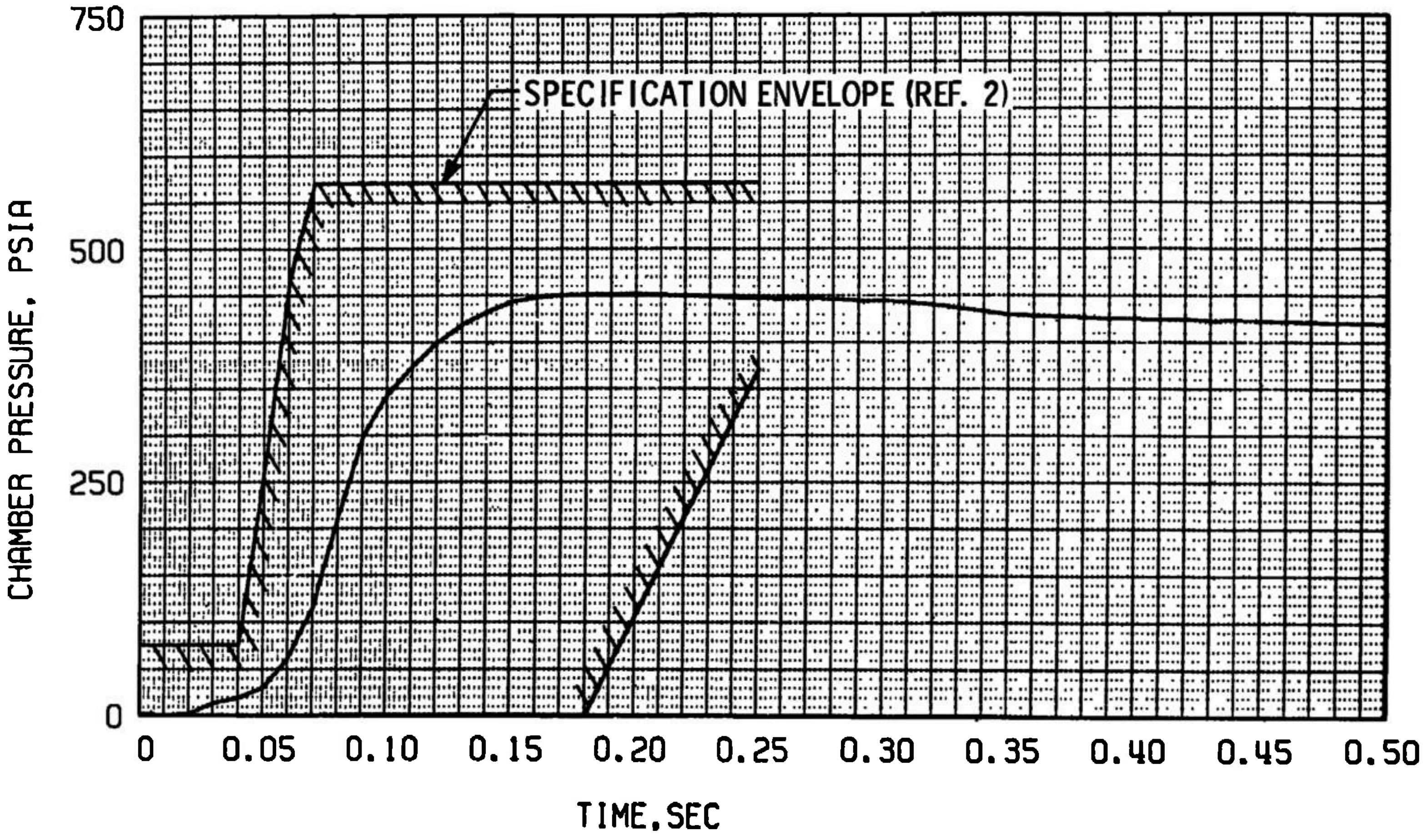


Fig. 10 Chamber Pressure during Ignition Transient

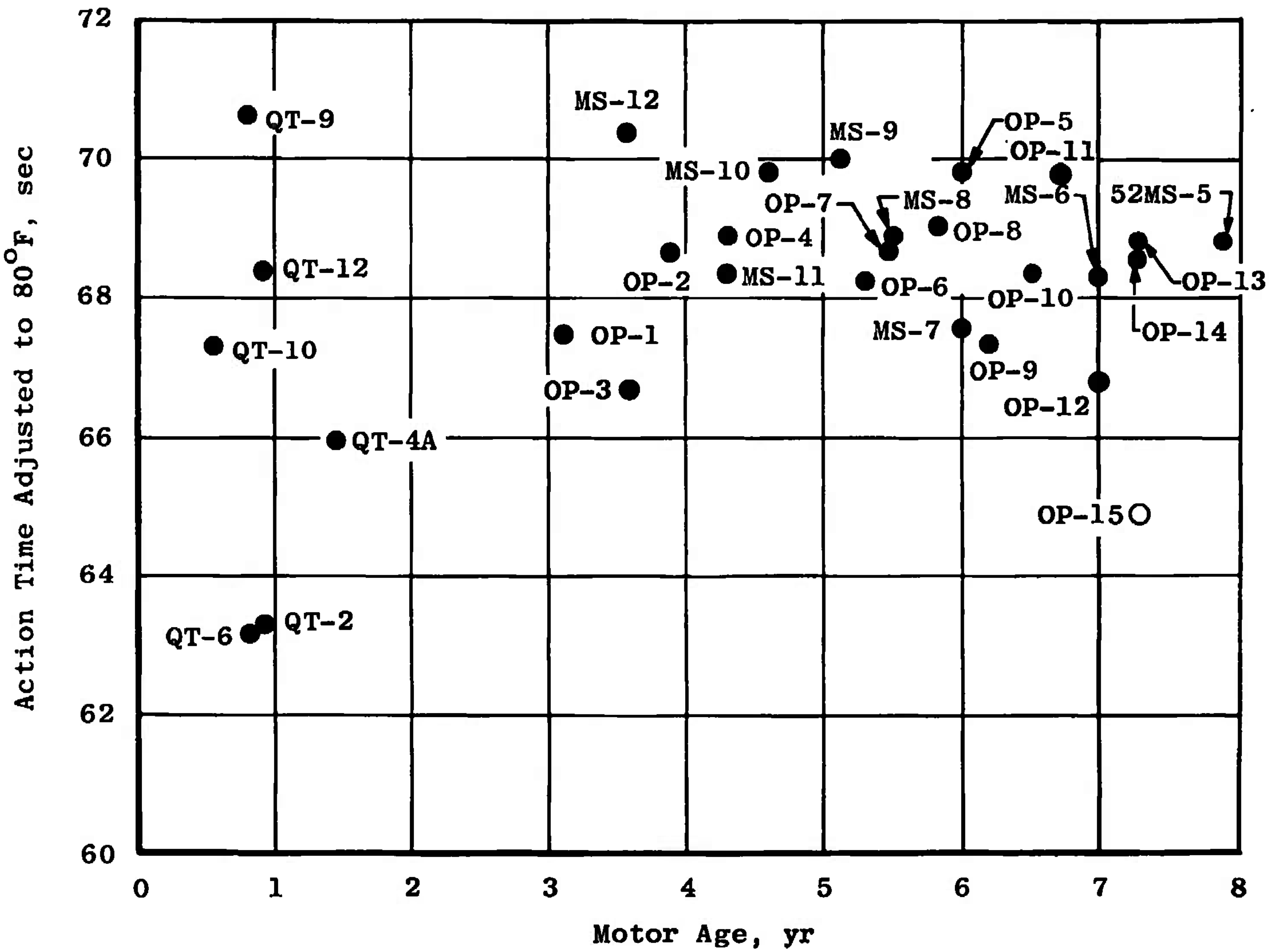


Fig. 11 Motor Action Time versus Age for Minuteman LGM-30F Stage II Motors Fired at AEDC

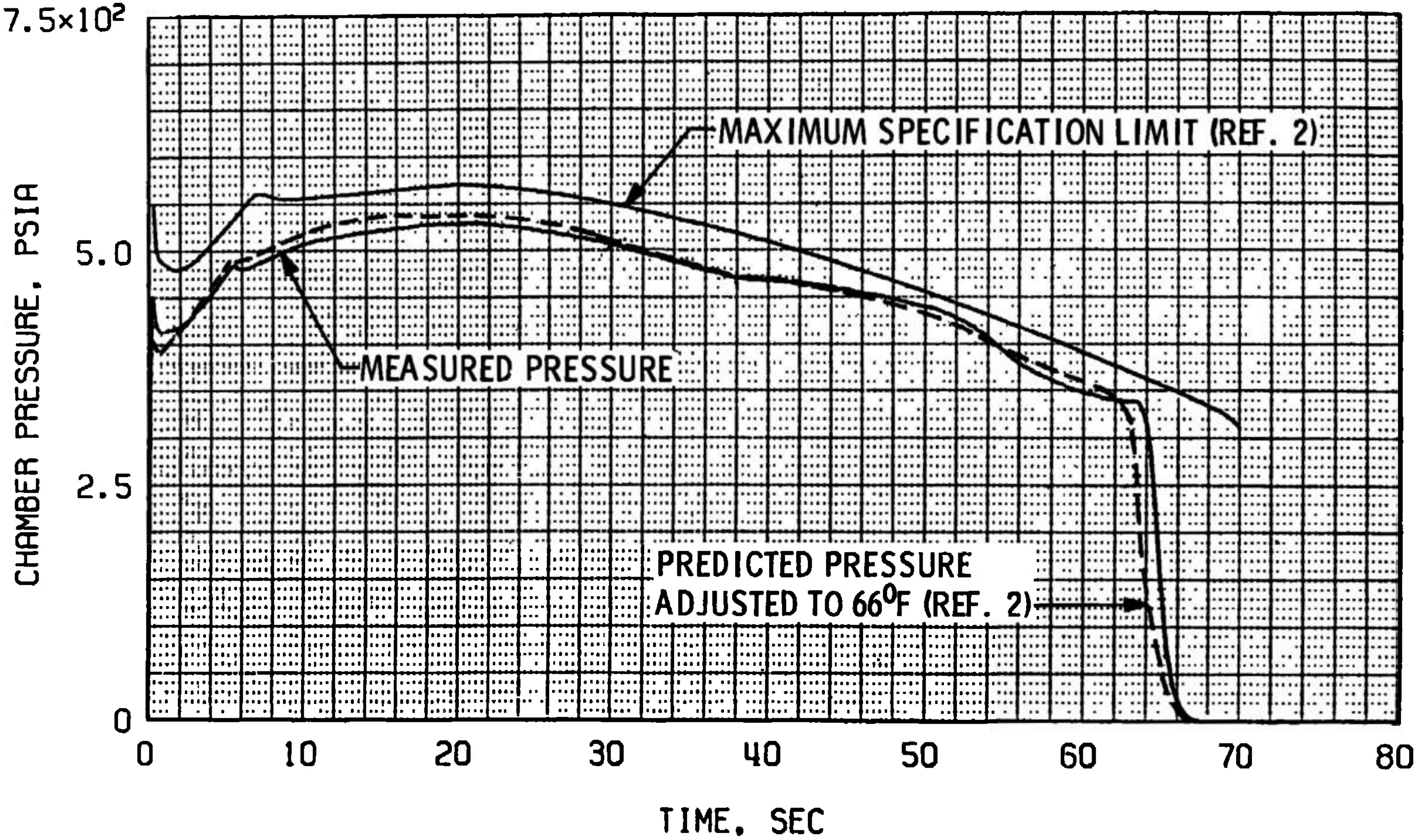


Fig. 12 Chamber Pressure; Measured, Predicted, and Maximum Specification

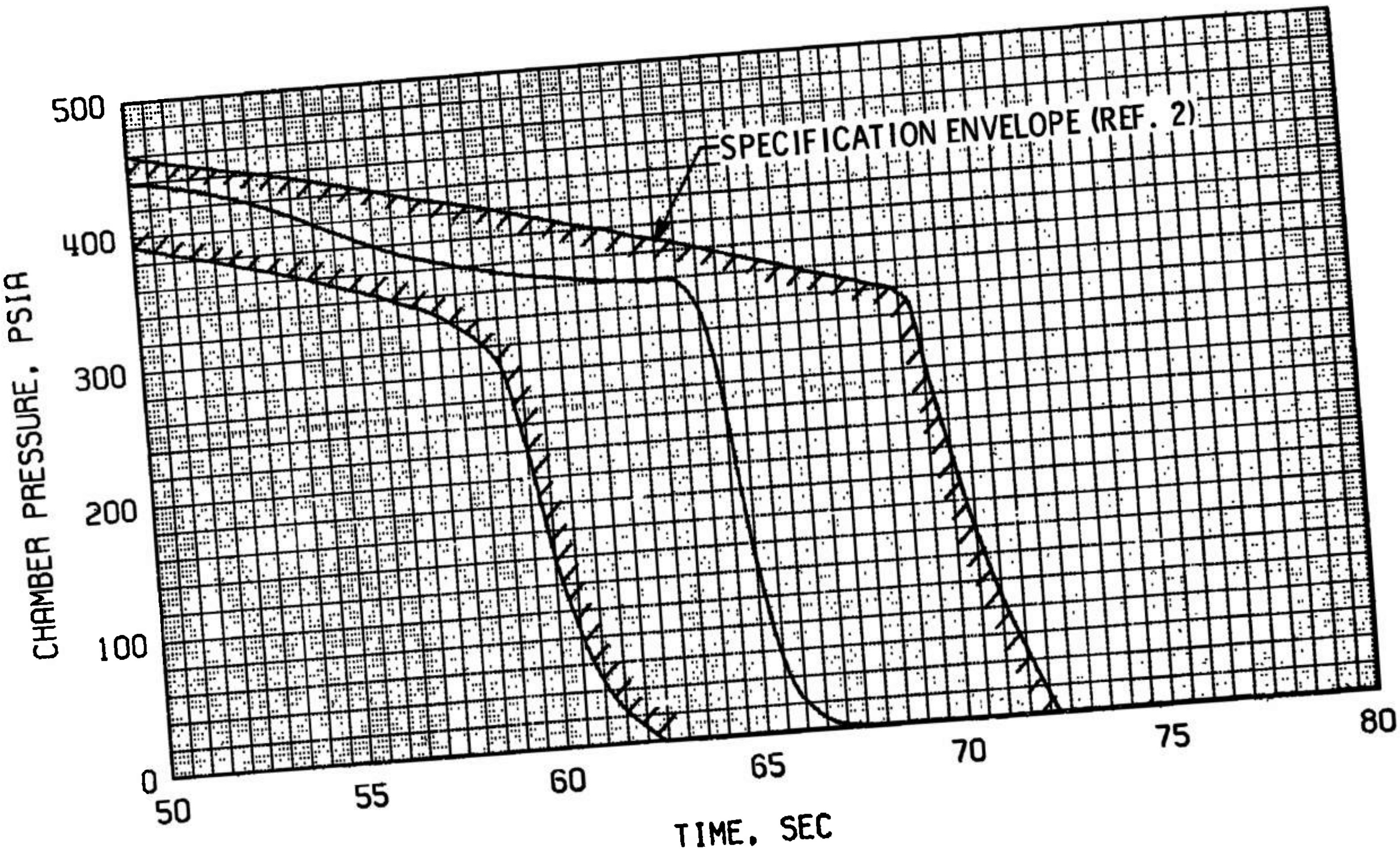


Fig. 13 Chamber Pressure Decay and Specification Envelope

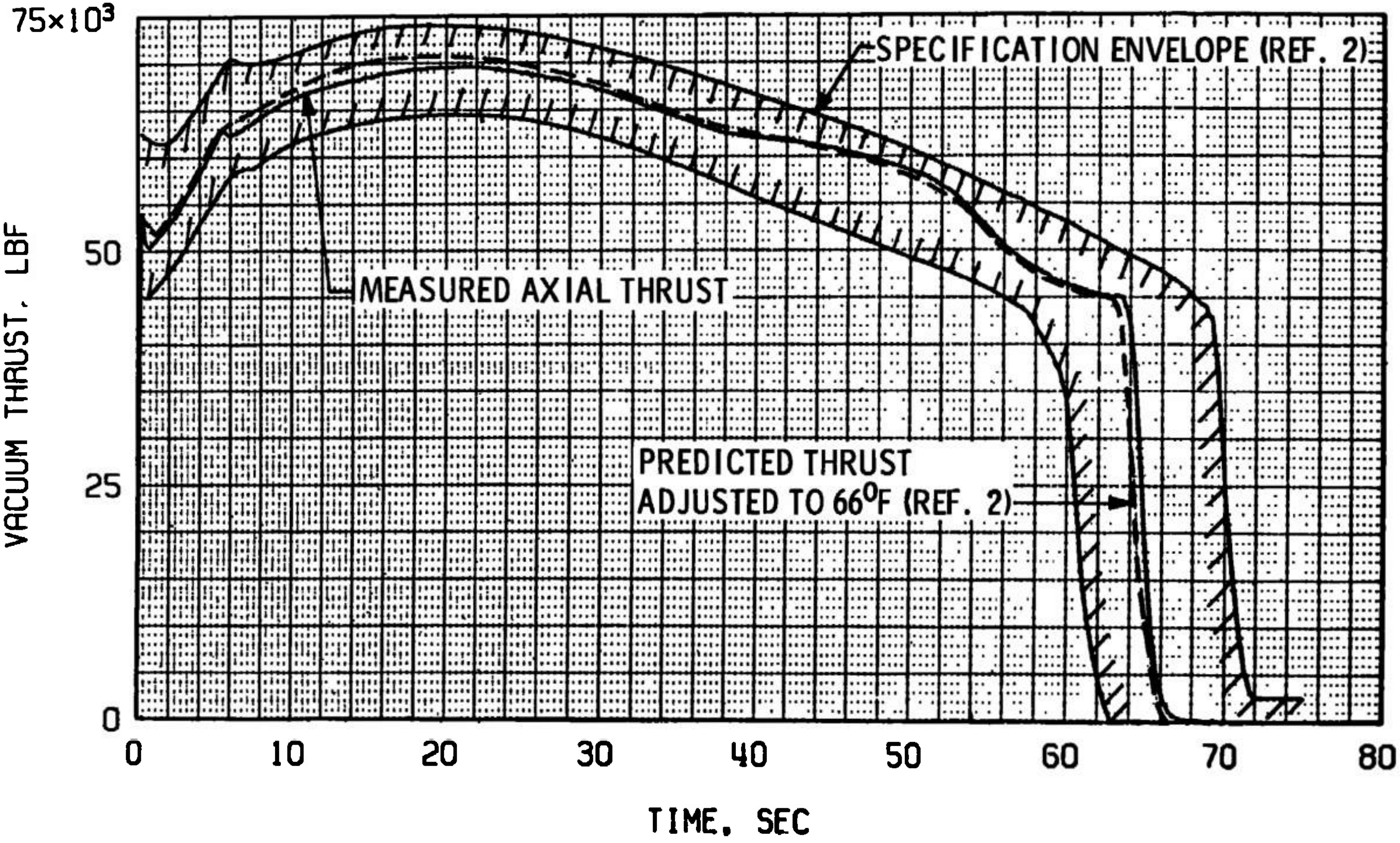


Fig. 14 Vacuum Thrust; Measured Axial, Predicted, and Specification Envelope

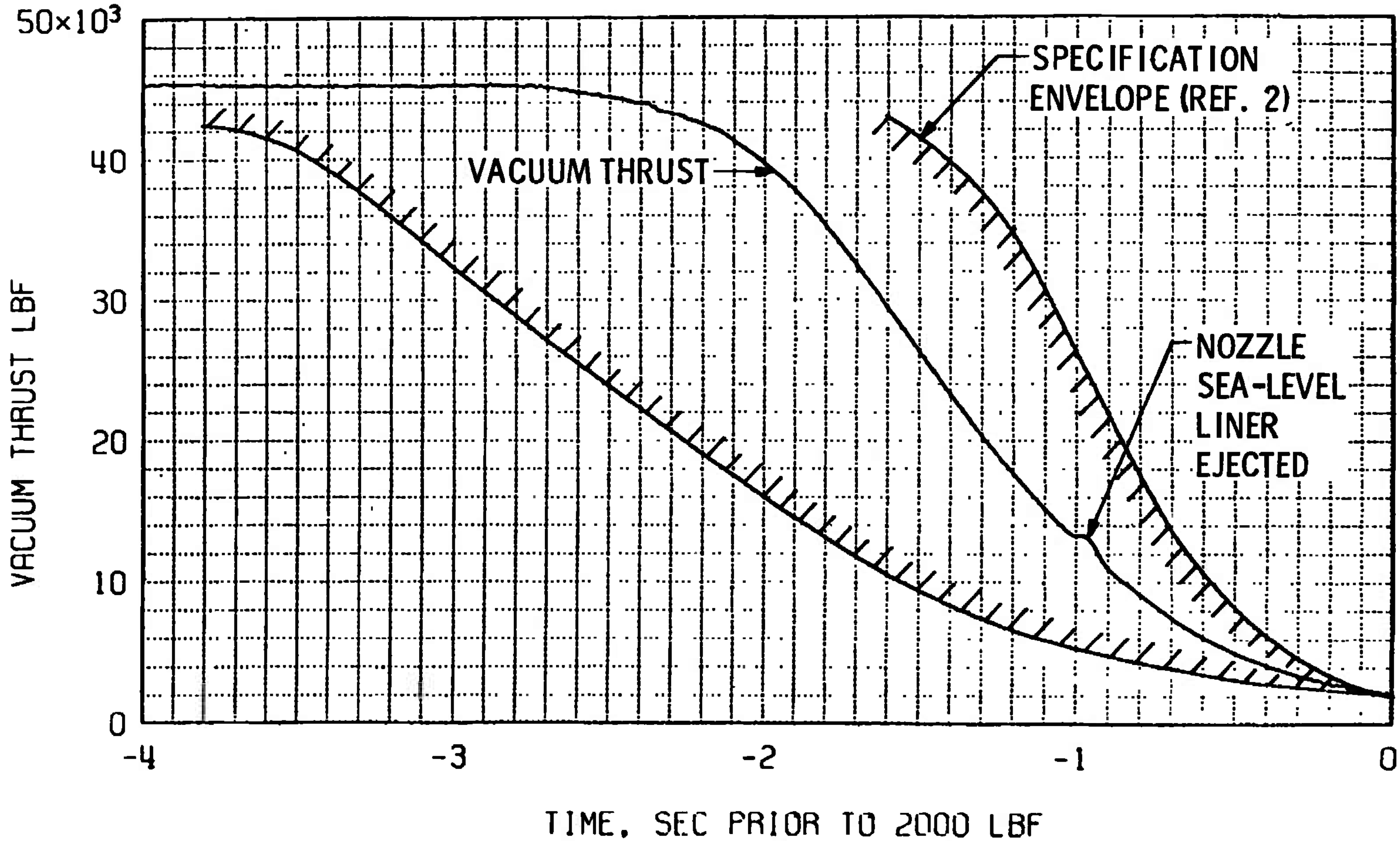


Fig. 15 Vacuum Thrust Tailoff and Specification Envelope

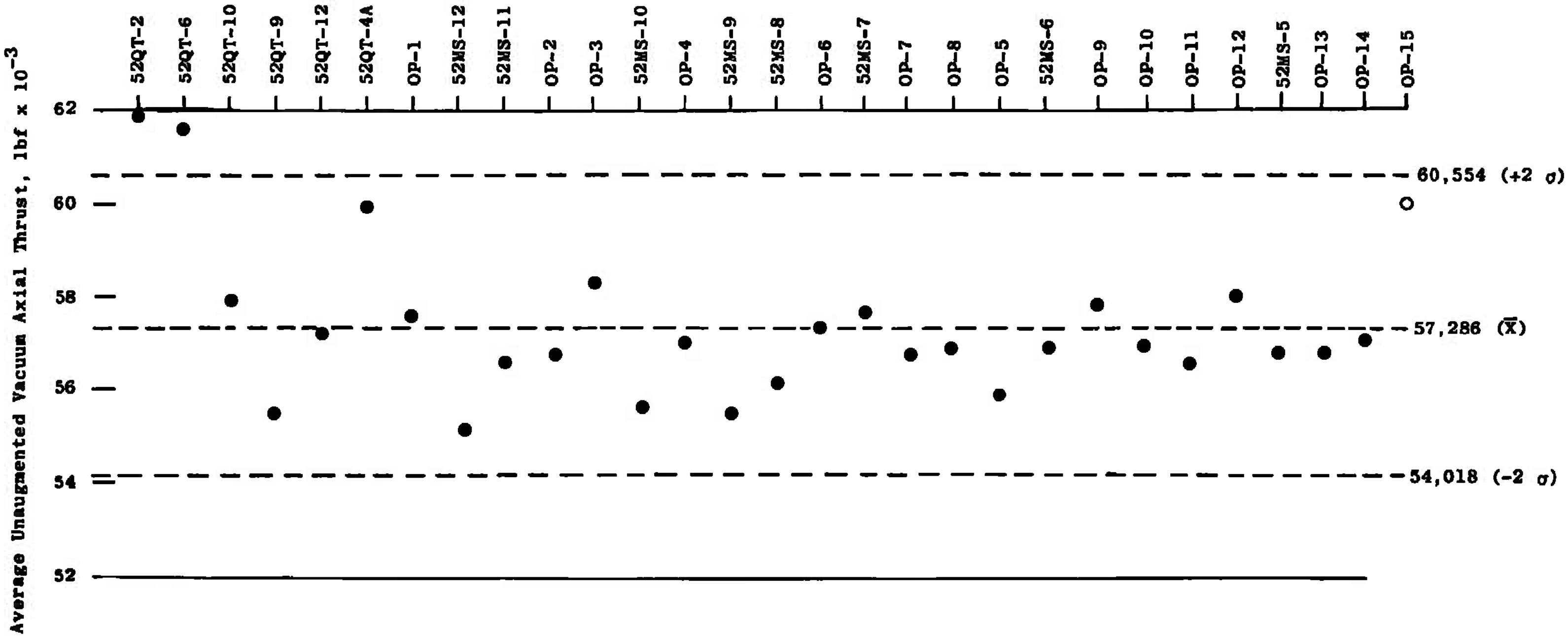


Fig. 16 Average Vacuum Axial-Thrust Statistical Data

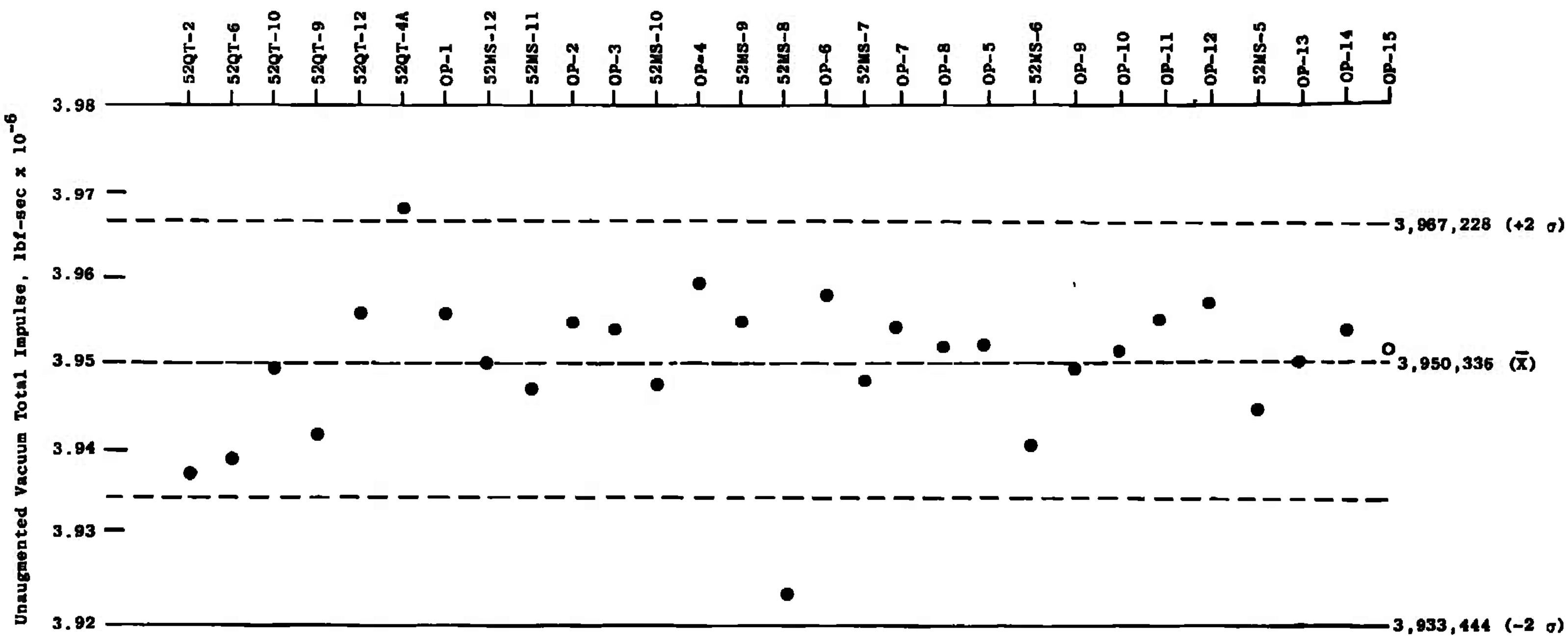


Fig. 17 Unaugmented Vacuum Total Impulse Statistical Data

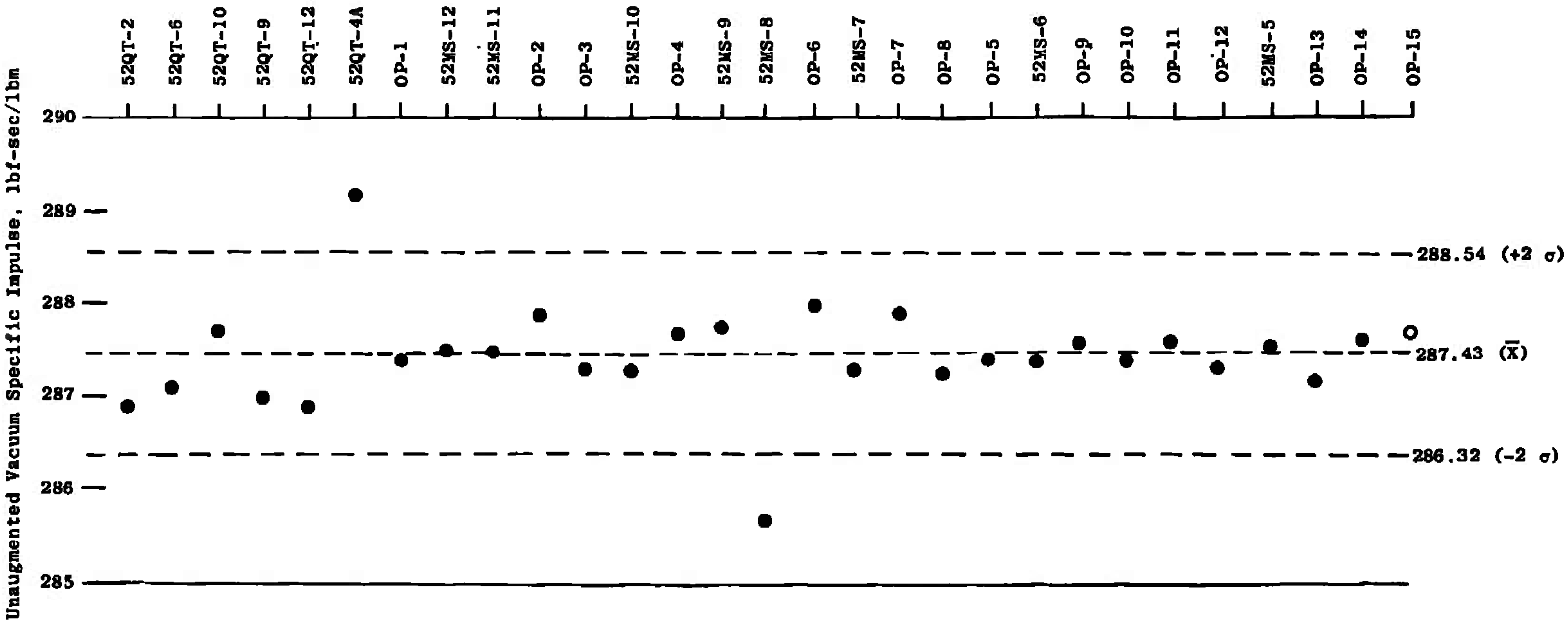


Fig. 18 Vacuum Specific Impulse Statistical Data

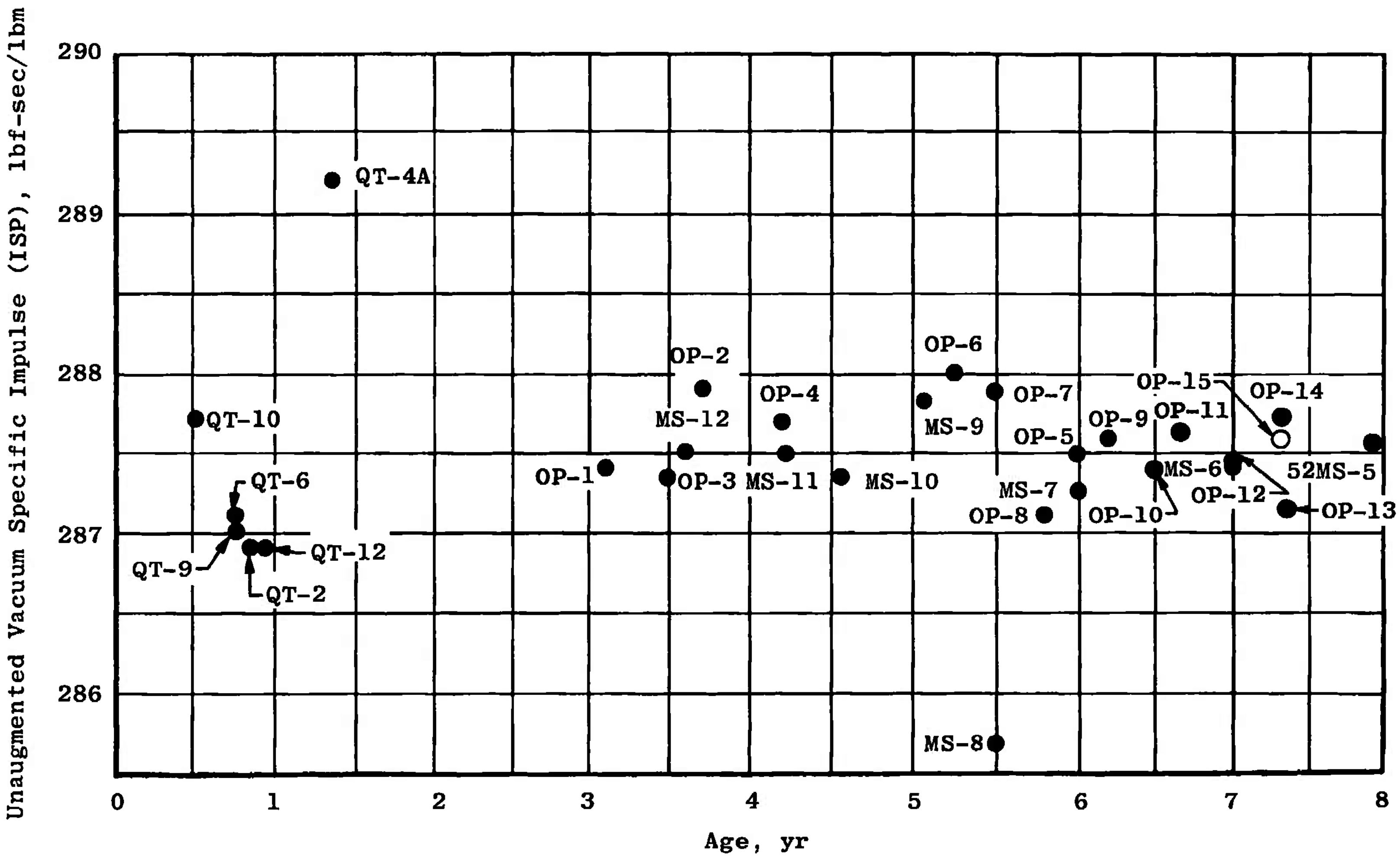


Fig. 19 Specific Impulse versus Age for Minuteman LGM-30F Stage II Motors Fired at AEDC

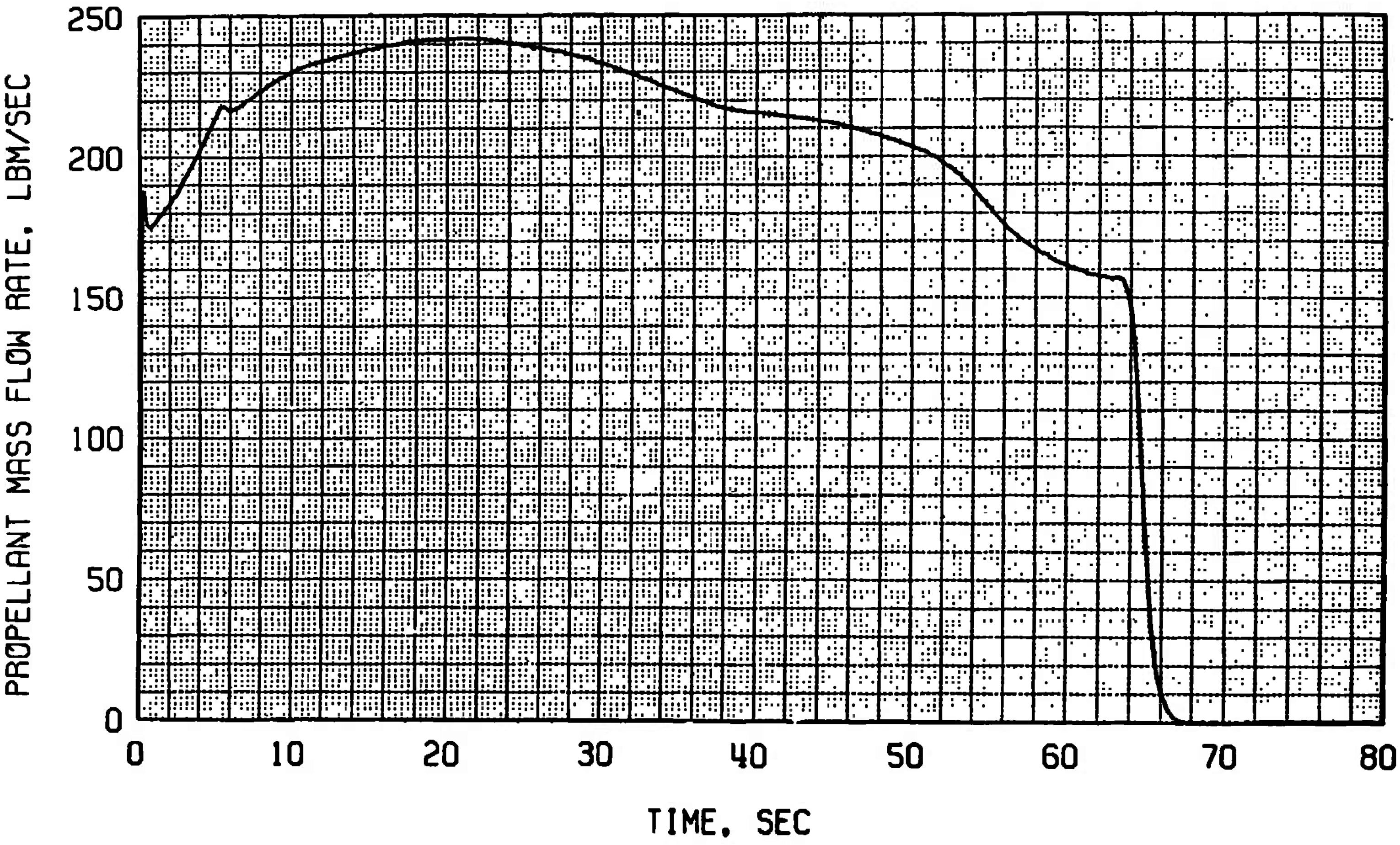
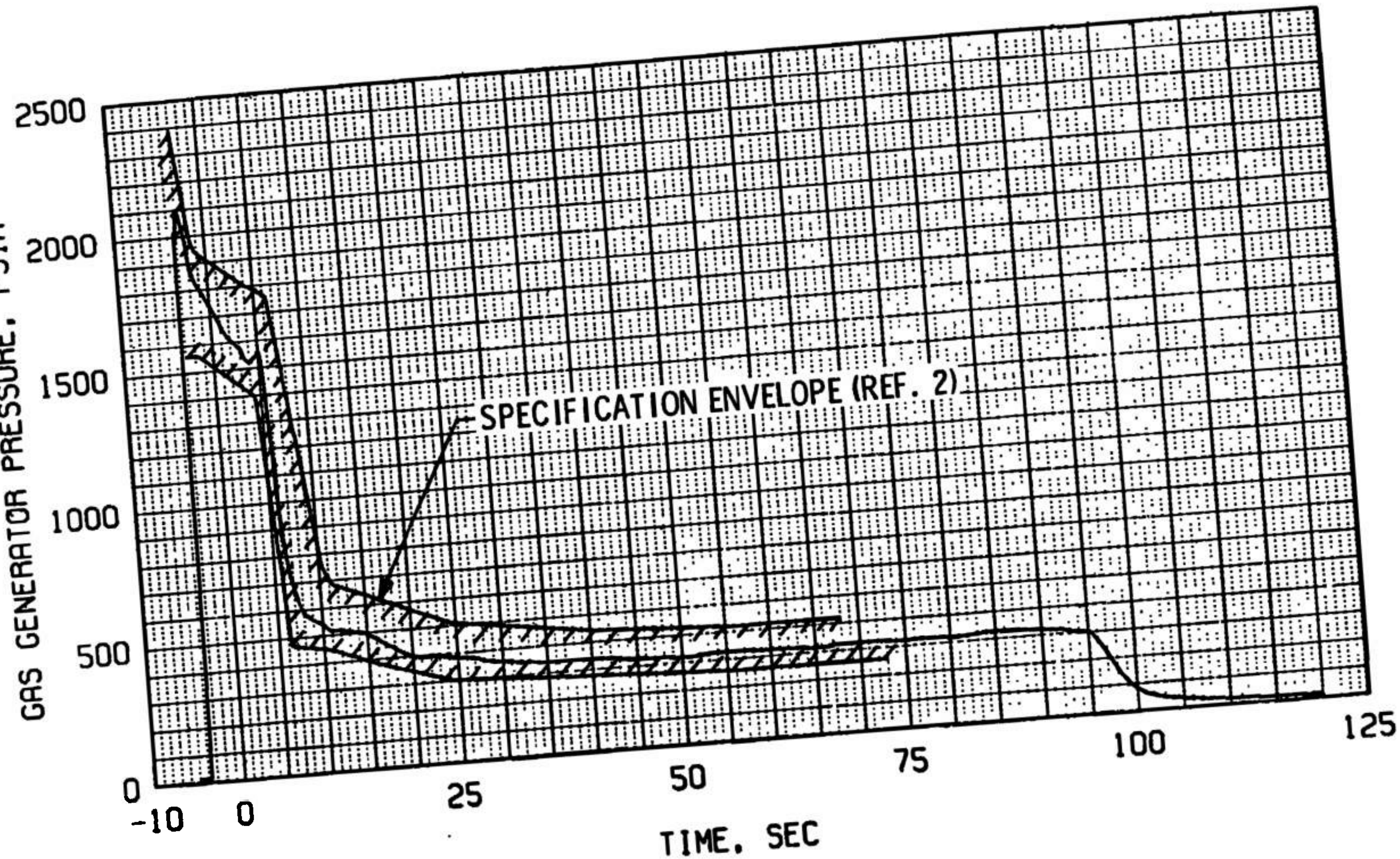
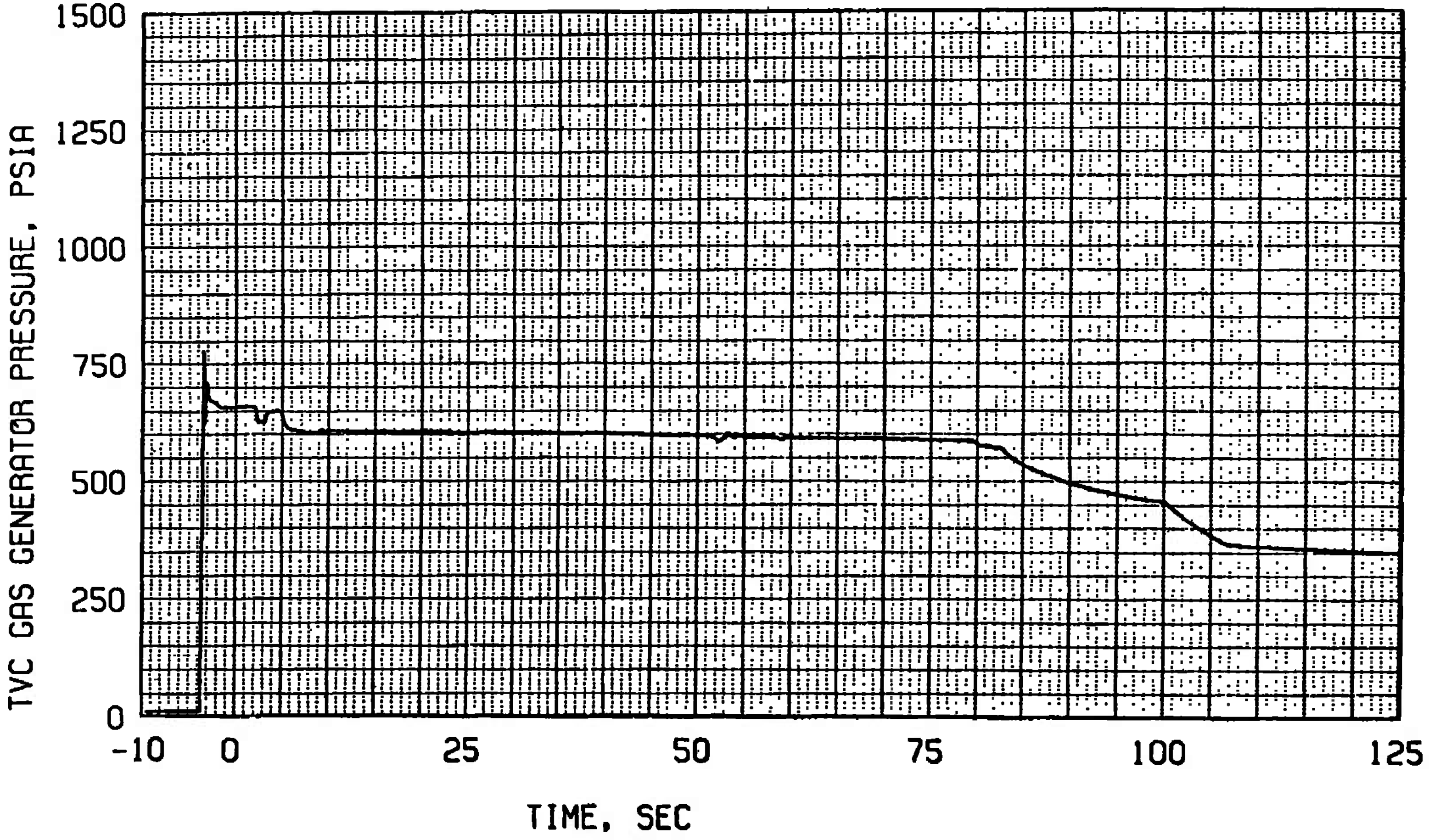


Fig. 20 Propellant Exhaust Mass Flow Rate



a. RC System

Fig. 21 Gas Generator Pressures



b. LITVC System
Fig. 21 Concluded

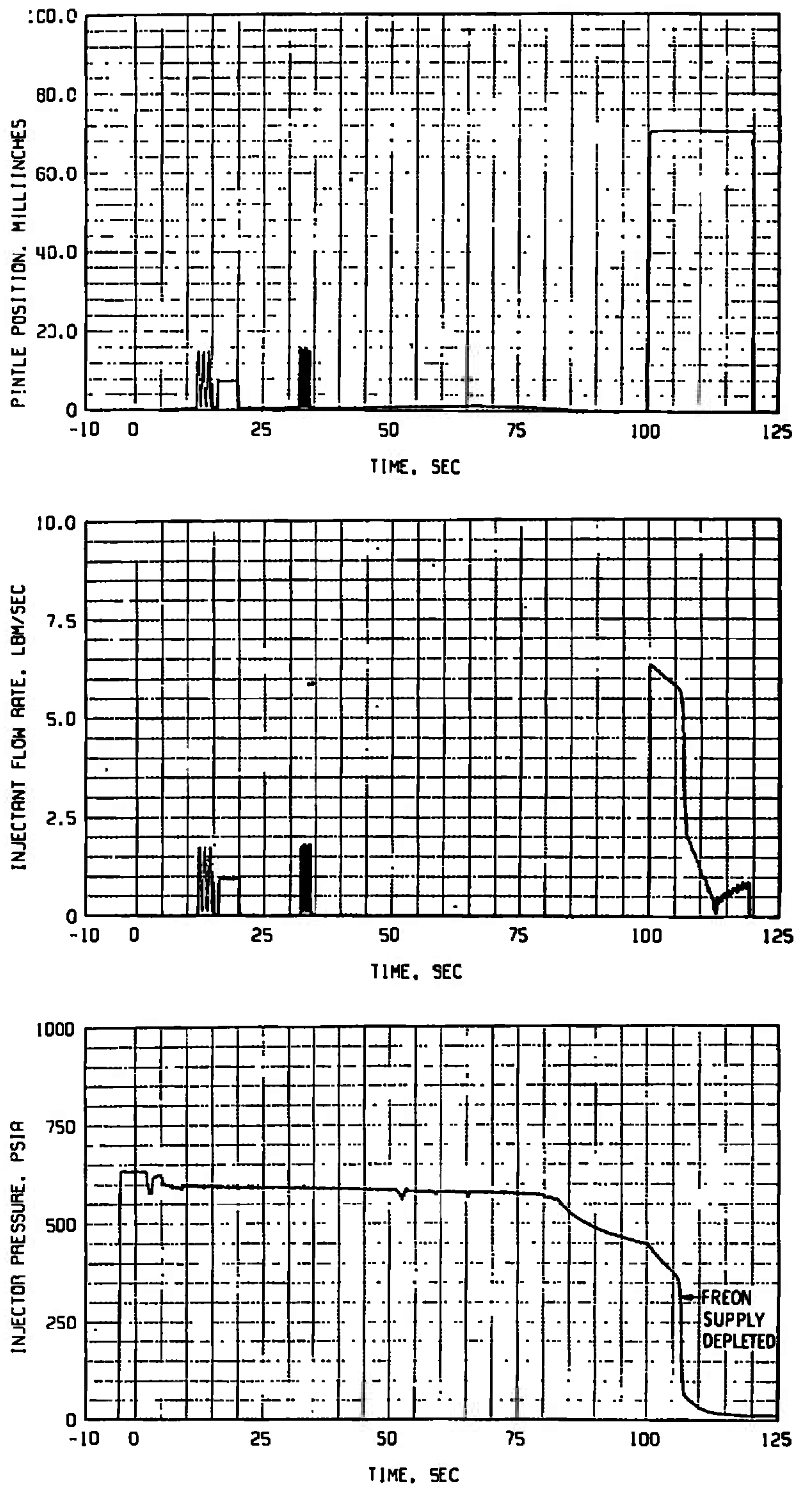


Fig. 22 Liquid-Injection Thrust Vector Control Data Summary for Injector Valve 1 (0 deg)

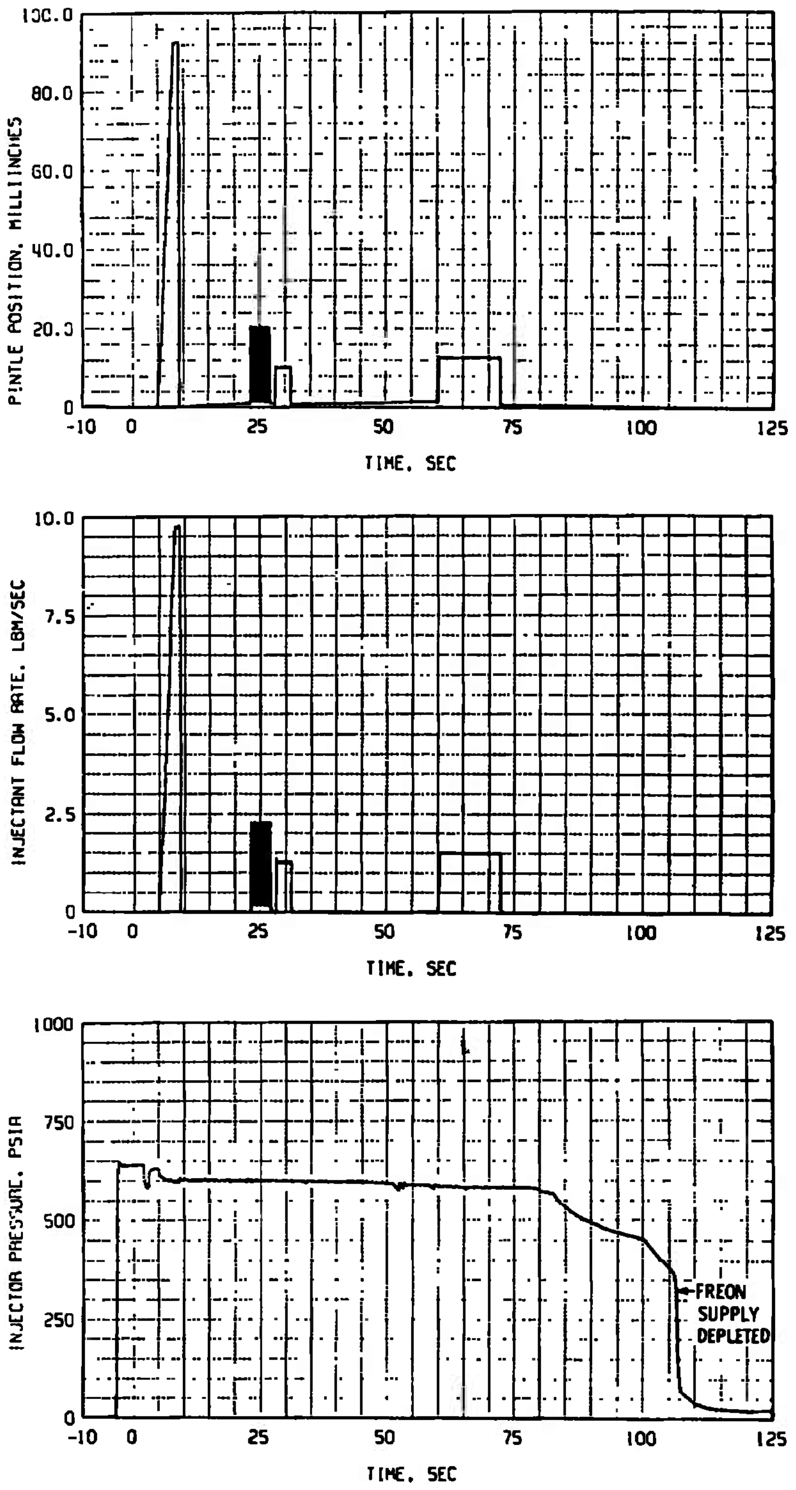


Fig. 23 Liquid-Injection Thrust Vector Control Data Summary for Injector Valve 2 (90 deg)

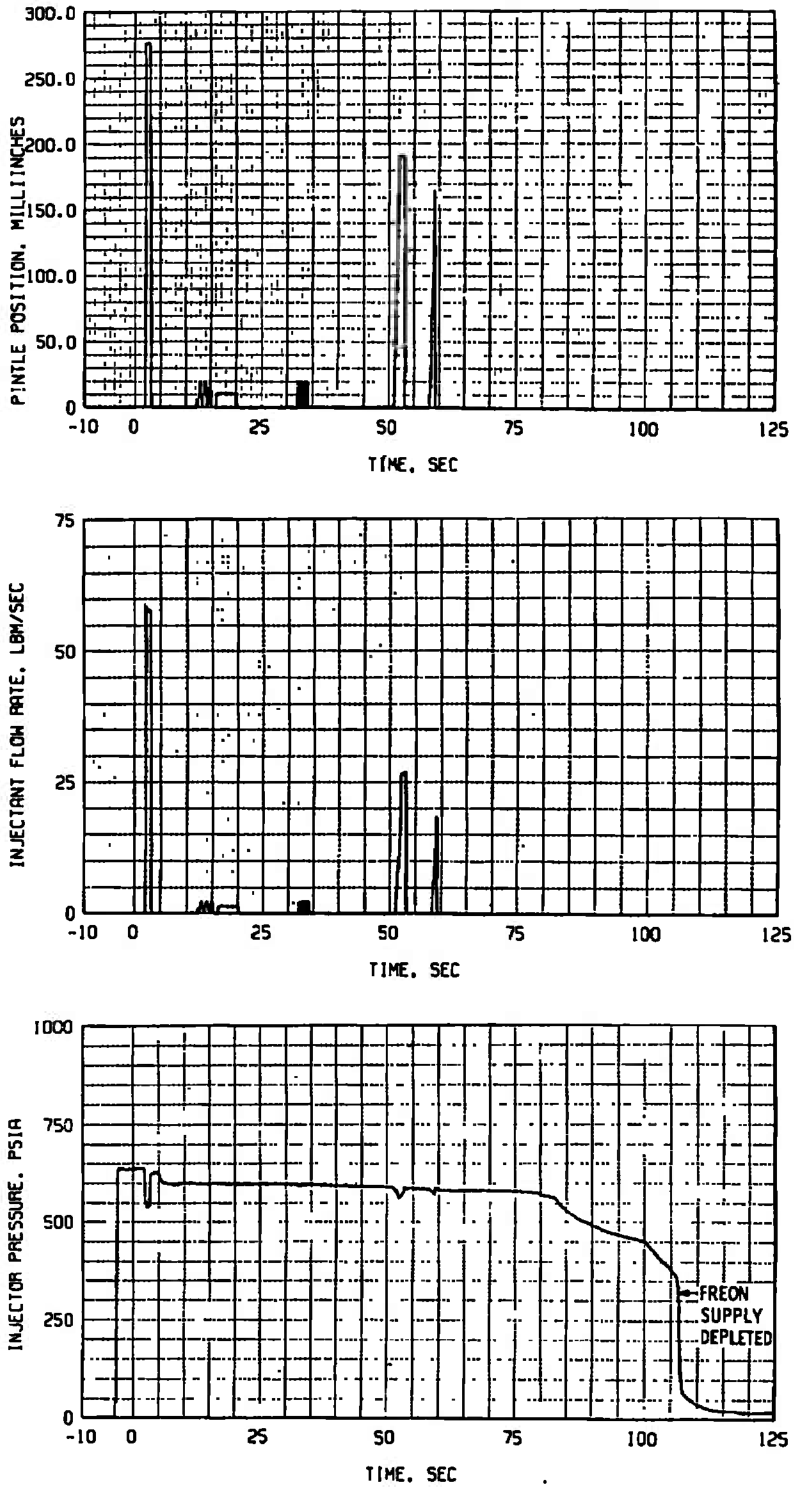


Fig. 24 Liquid-Injection Thrust Vector Control Data Summary for Injector Valve 4 (270 deg)

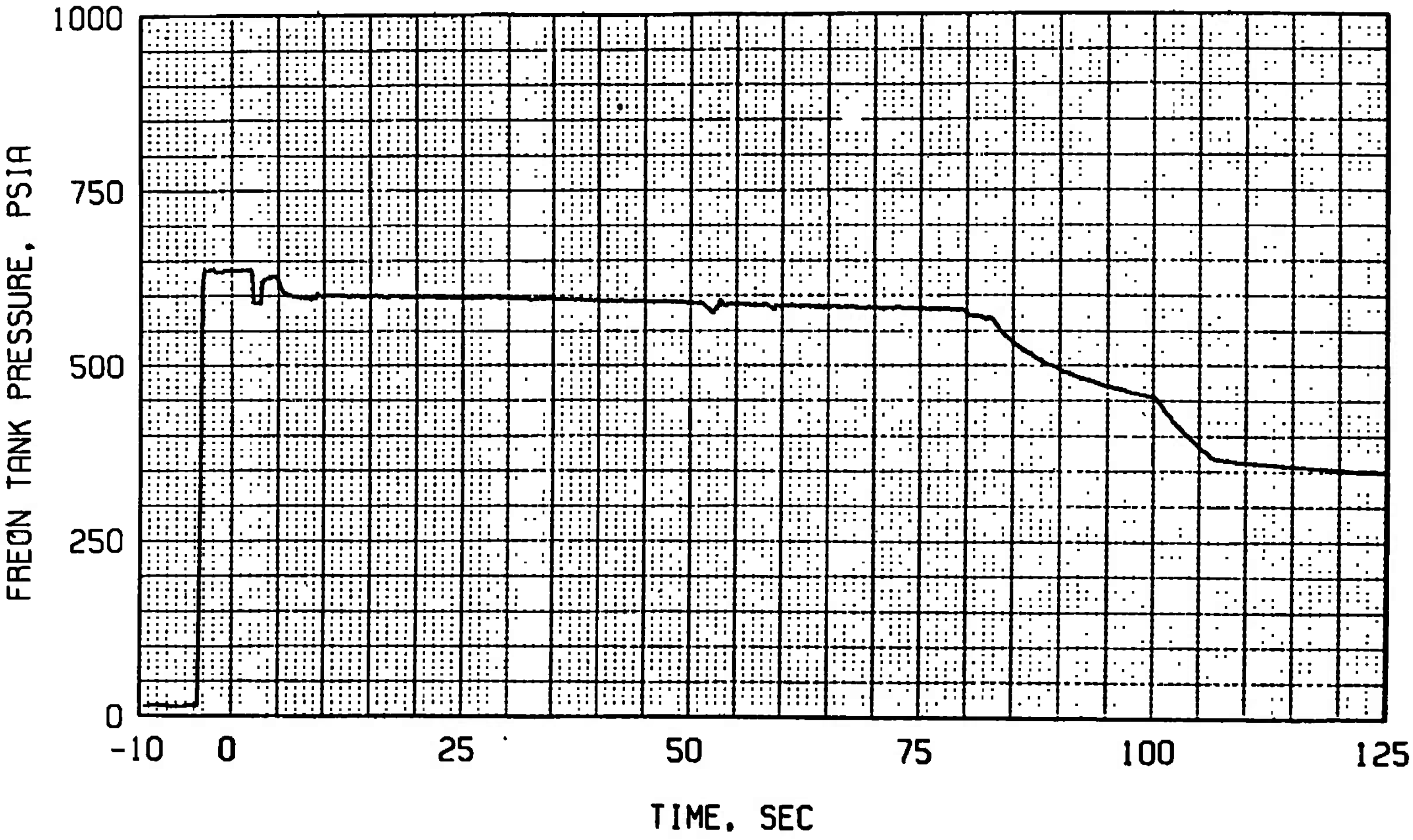


Fig. 25 LITVC Freon Tank Pressure

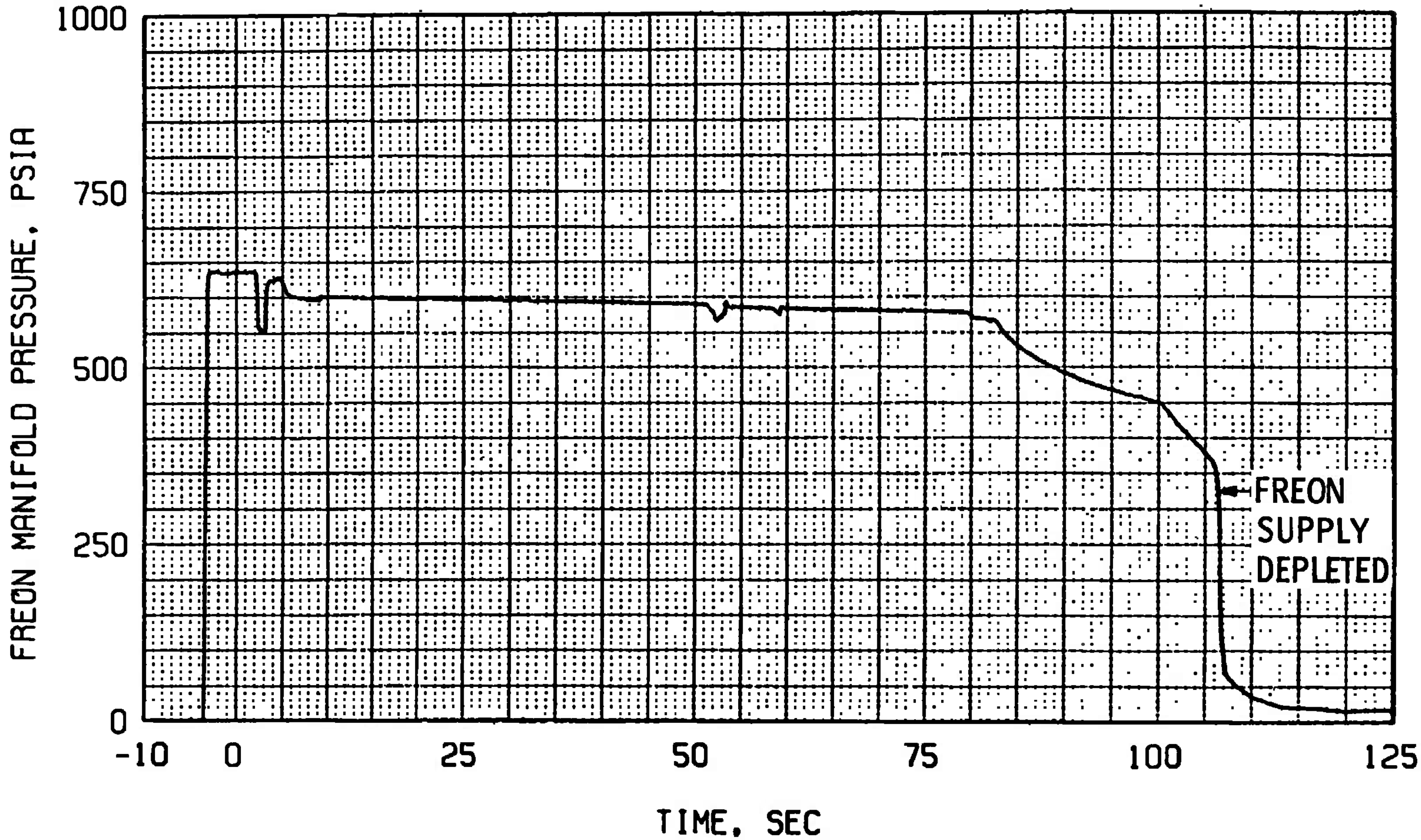


Fig. 26 LITVC Freon Manifold Pressure

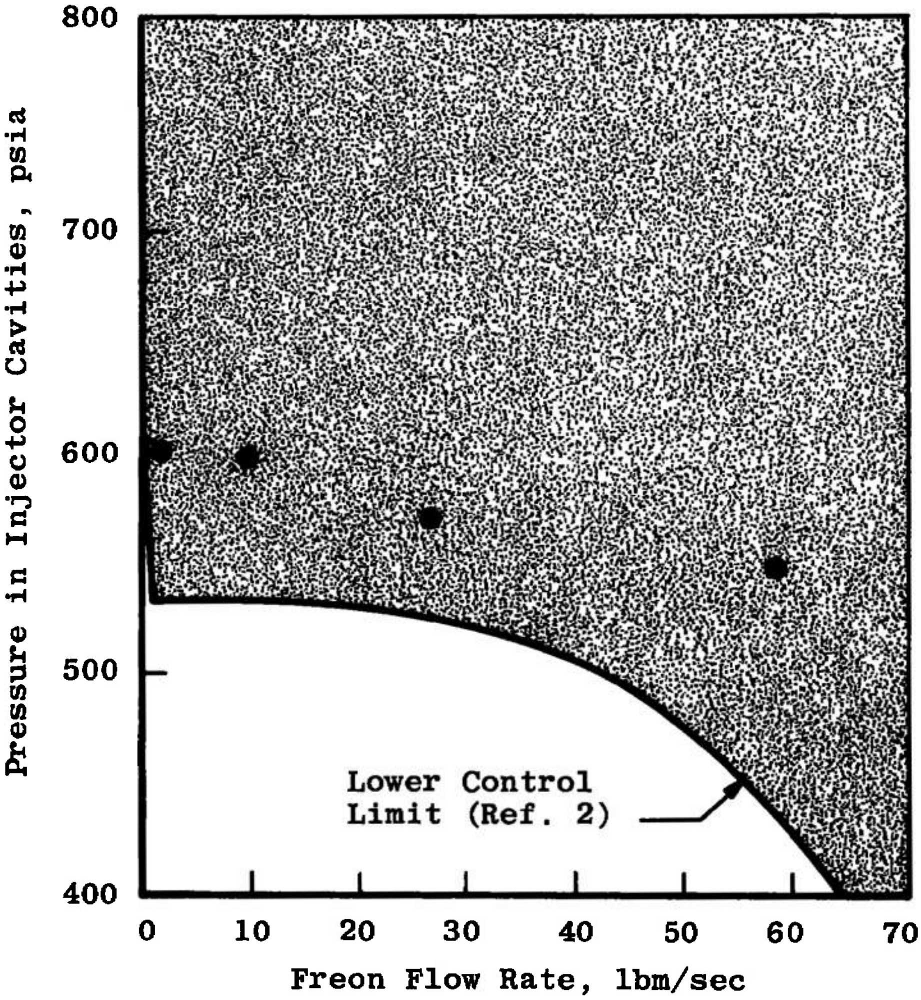


Fig. 27 Pressure in Injector Cavities versus Freon Flow Rate

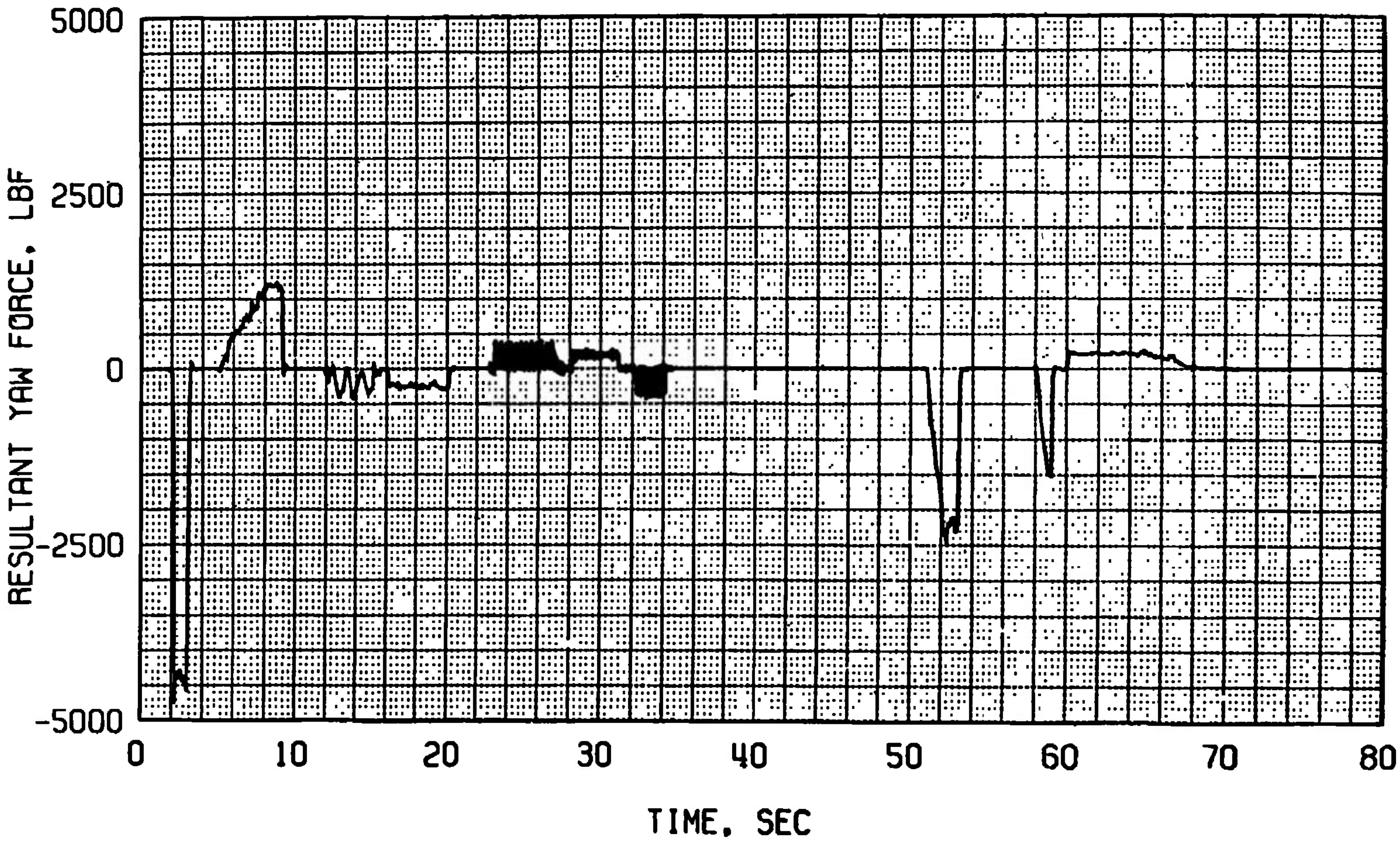


Fig. 28 Resultant Yaw Force

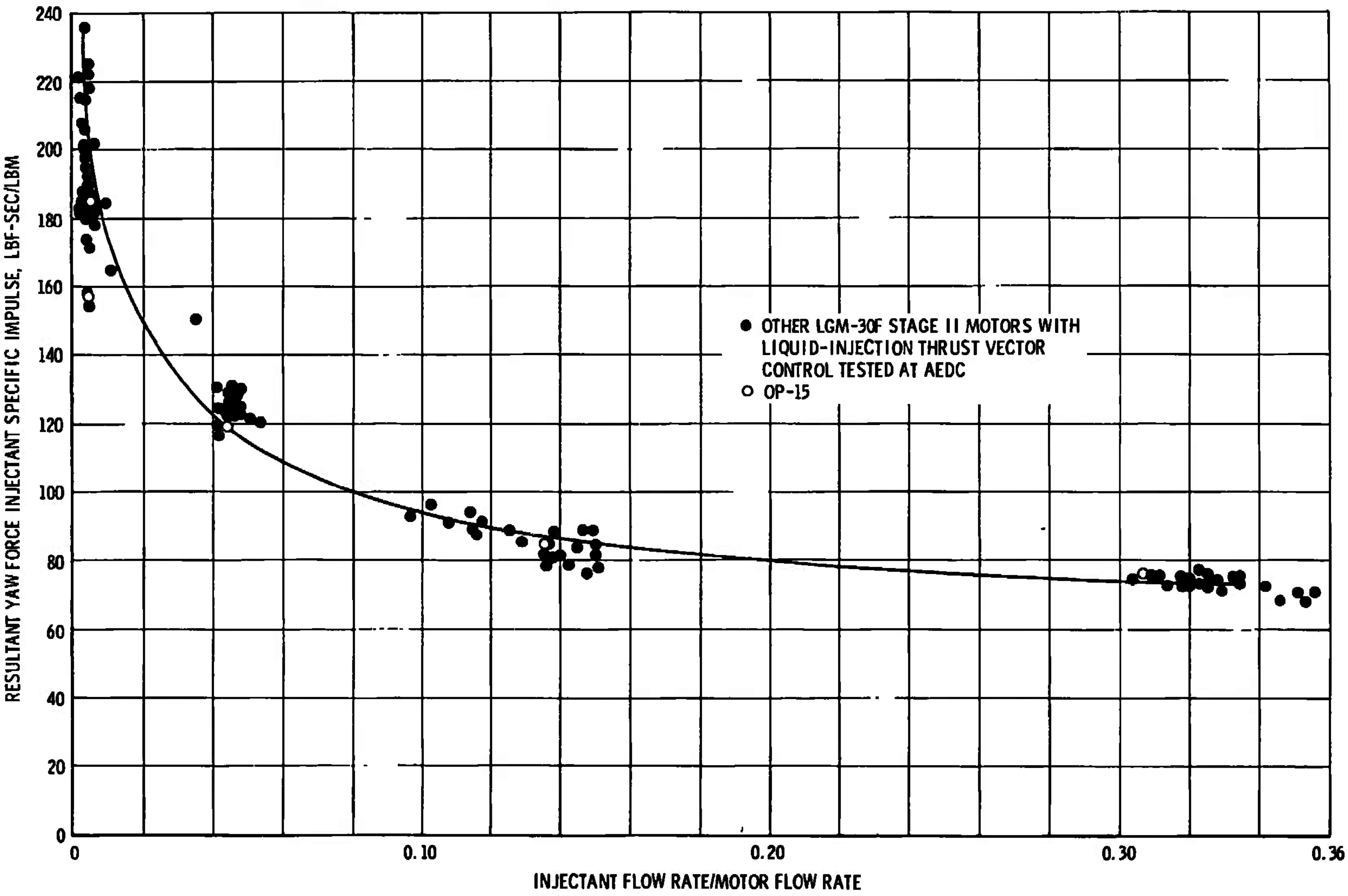


Fig. 29 Resultant Yaw Force Injectant Specific Impulse versus Injectant-to-Motor Flow Rate Ratio

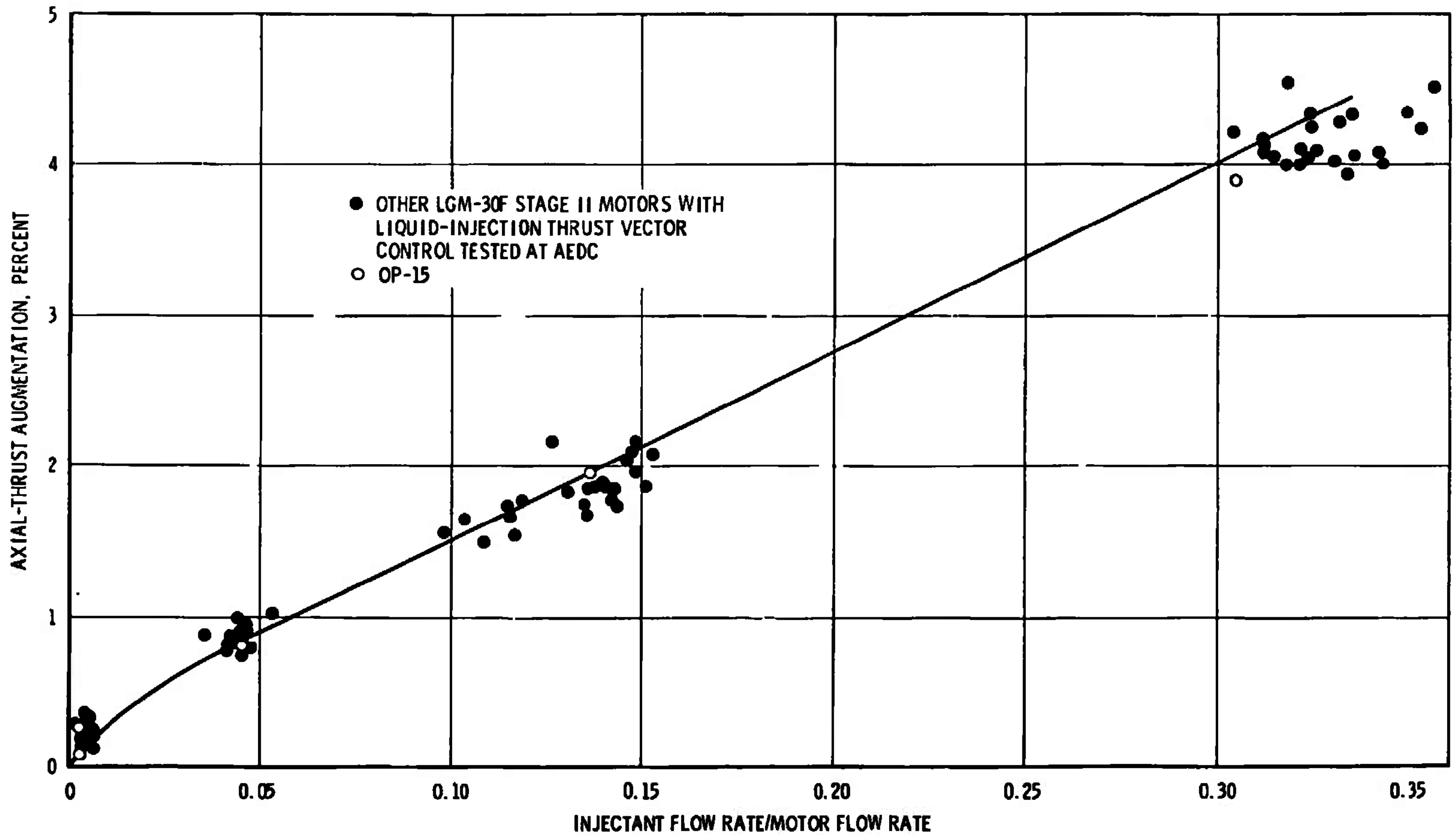


Fig. 30 Axial-Thrust Augmentation versus Injectant-to-Motor Flow Rate Ratio

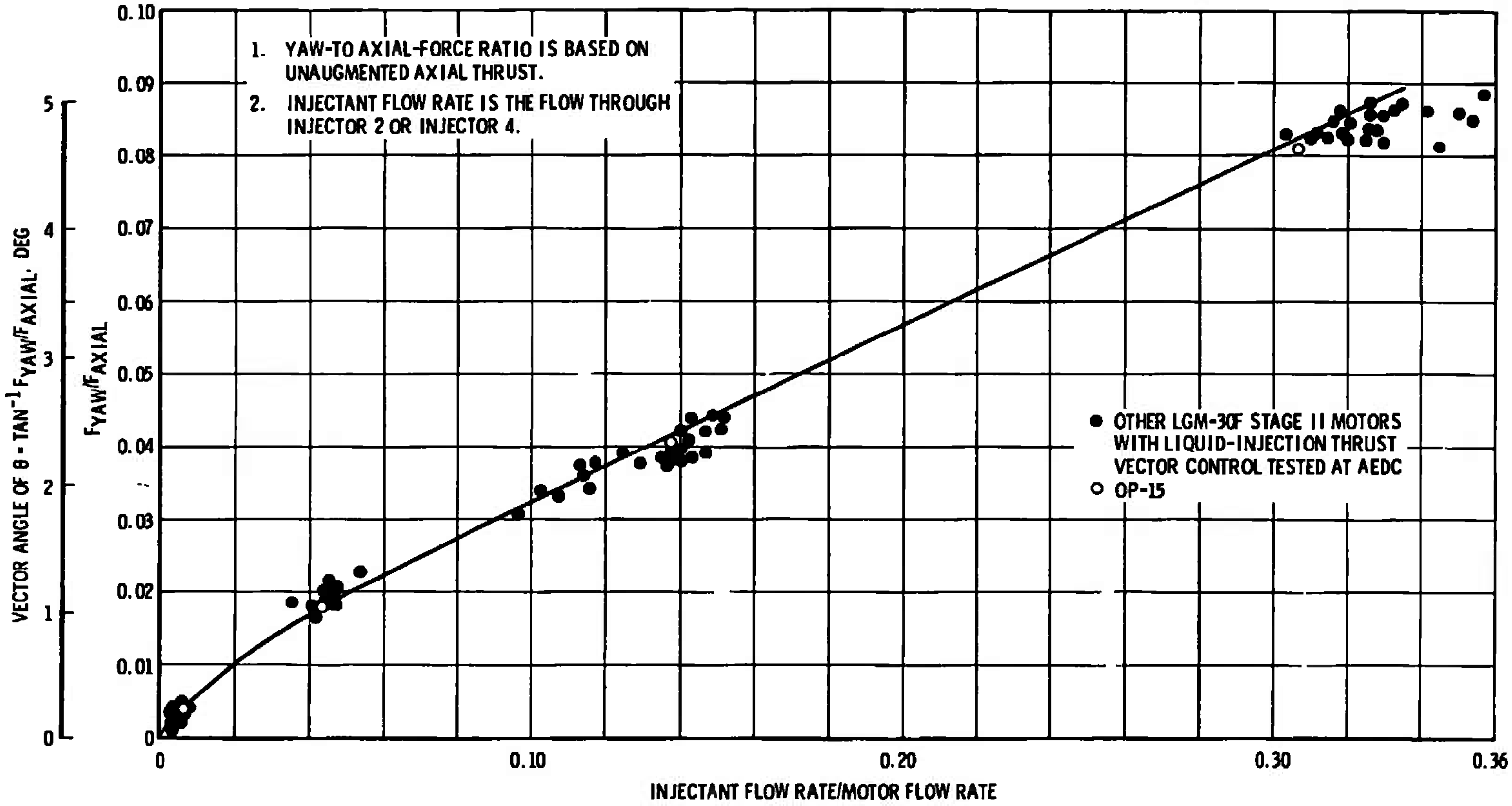


Fig. 31 Yaw- to Axial-Force Ratio versus Injectant-to-Motor Flow Rate Ratio

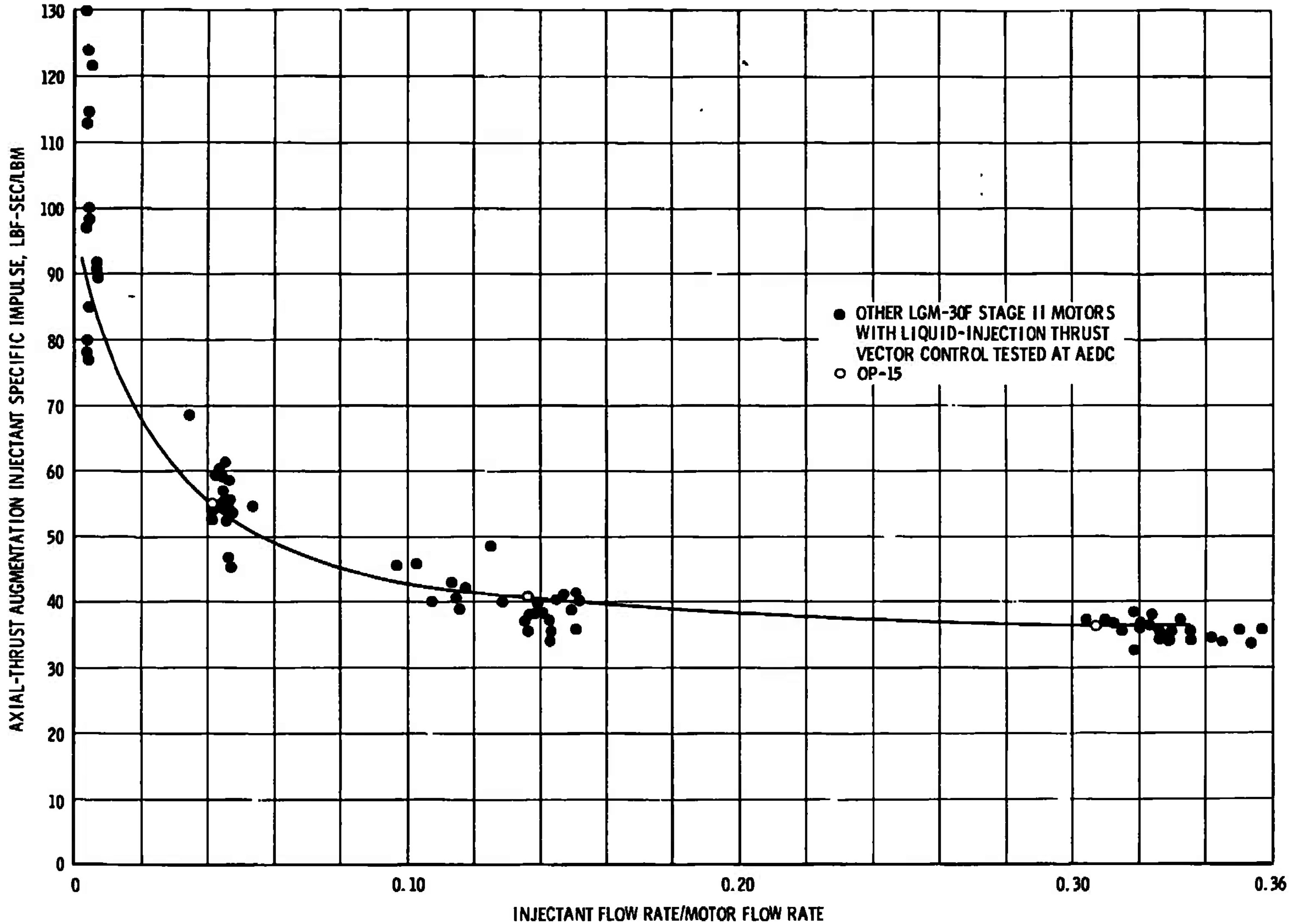
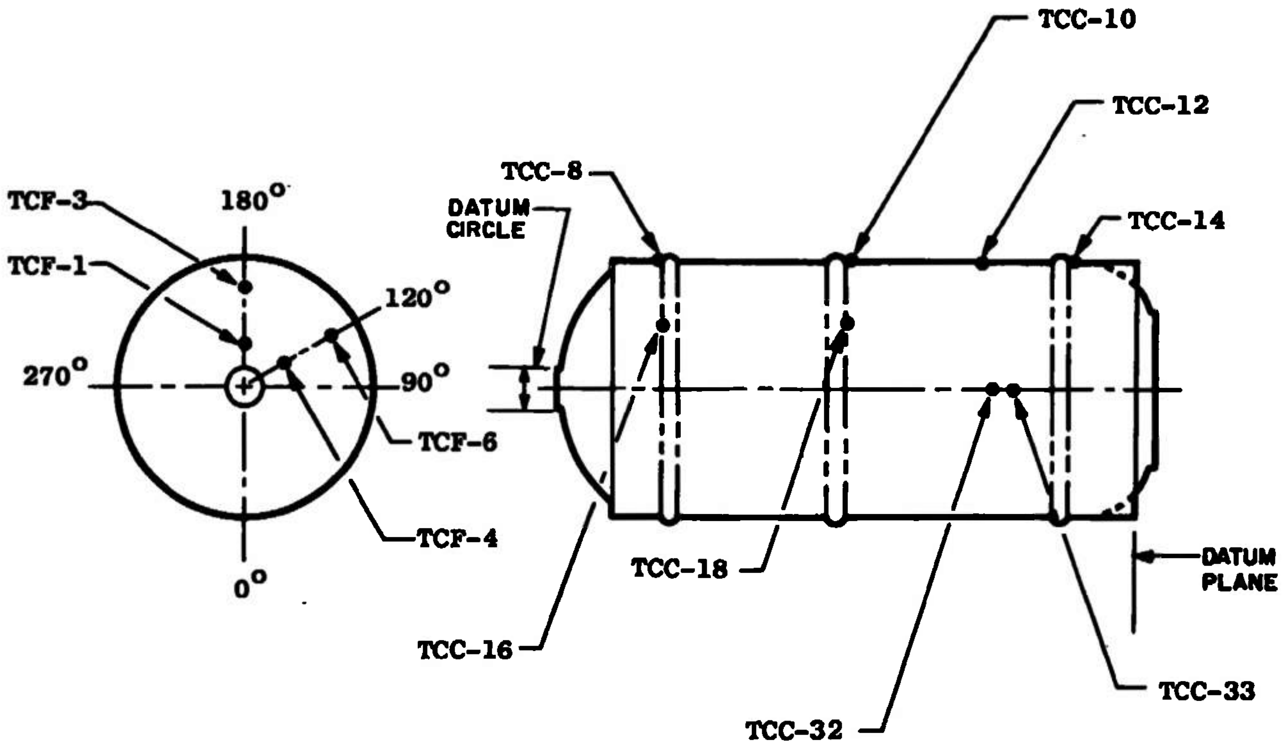


Fig. 32 Axial-Thrust Augmentation Injectant Specific Impulse versus Injectant-to-Motor Flow Rate Ratio

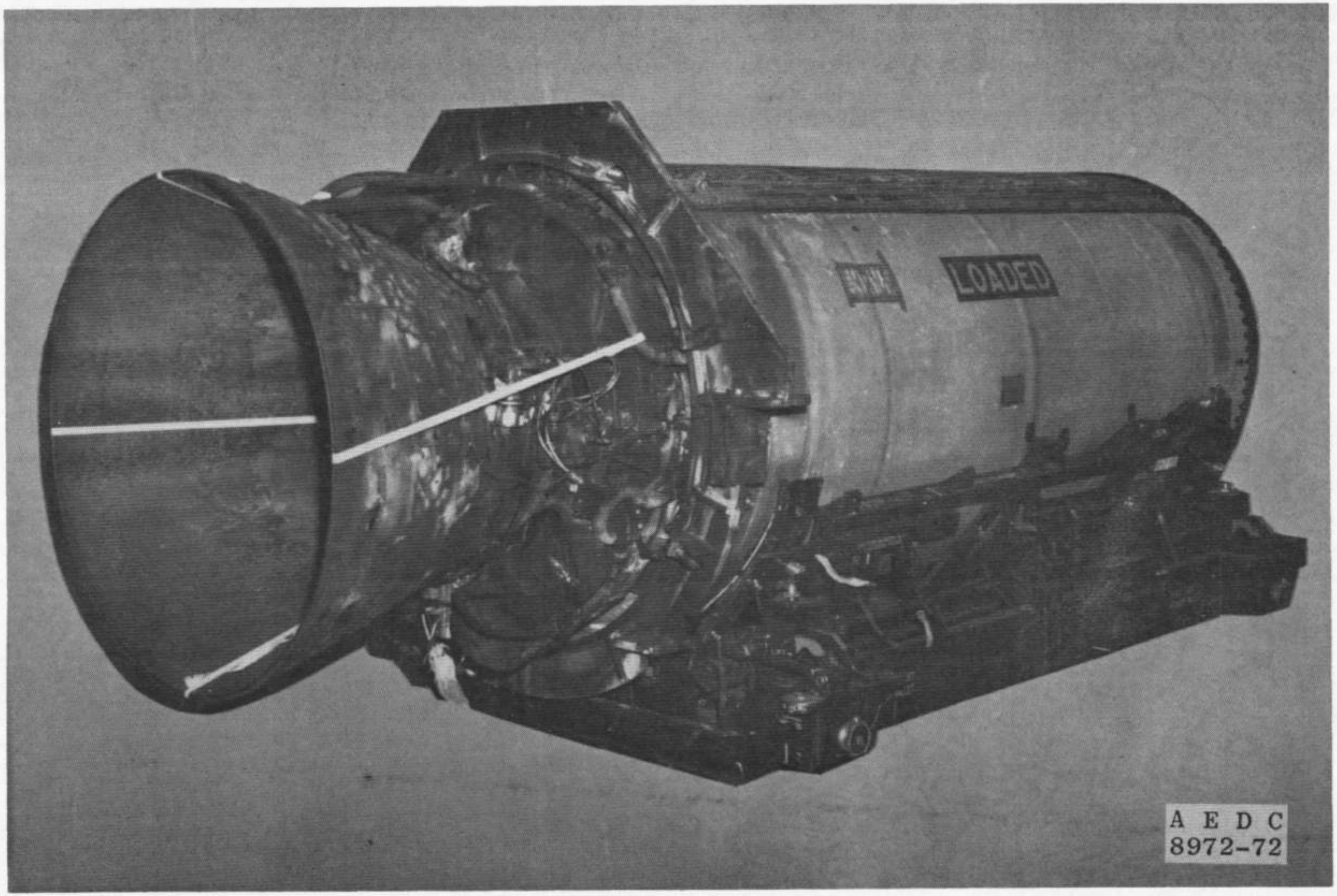


Thermocouple Locations for LGM-30F Stage II Motors

TCF-1	180° - 6.0 in.	TCC-12	180° - 33.0 in.
TCF-3	180° - 18.0	TCC-14	180° - 15.0
TCF-4	120° - 6.0	TCC-16	120° - 93.5
TCF-6	120° - 18.0	TCC-18	120° - 59.5
TCC-8	180° - 93.5	TCC-32	90° - 31.0
TCC-10	180° - 59.5	TCC-33	90° 28.0

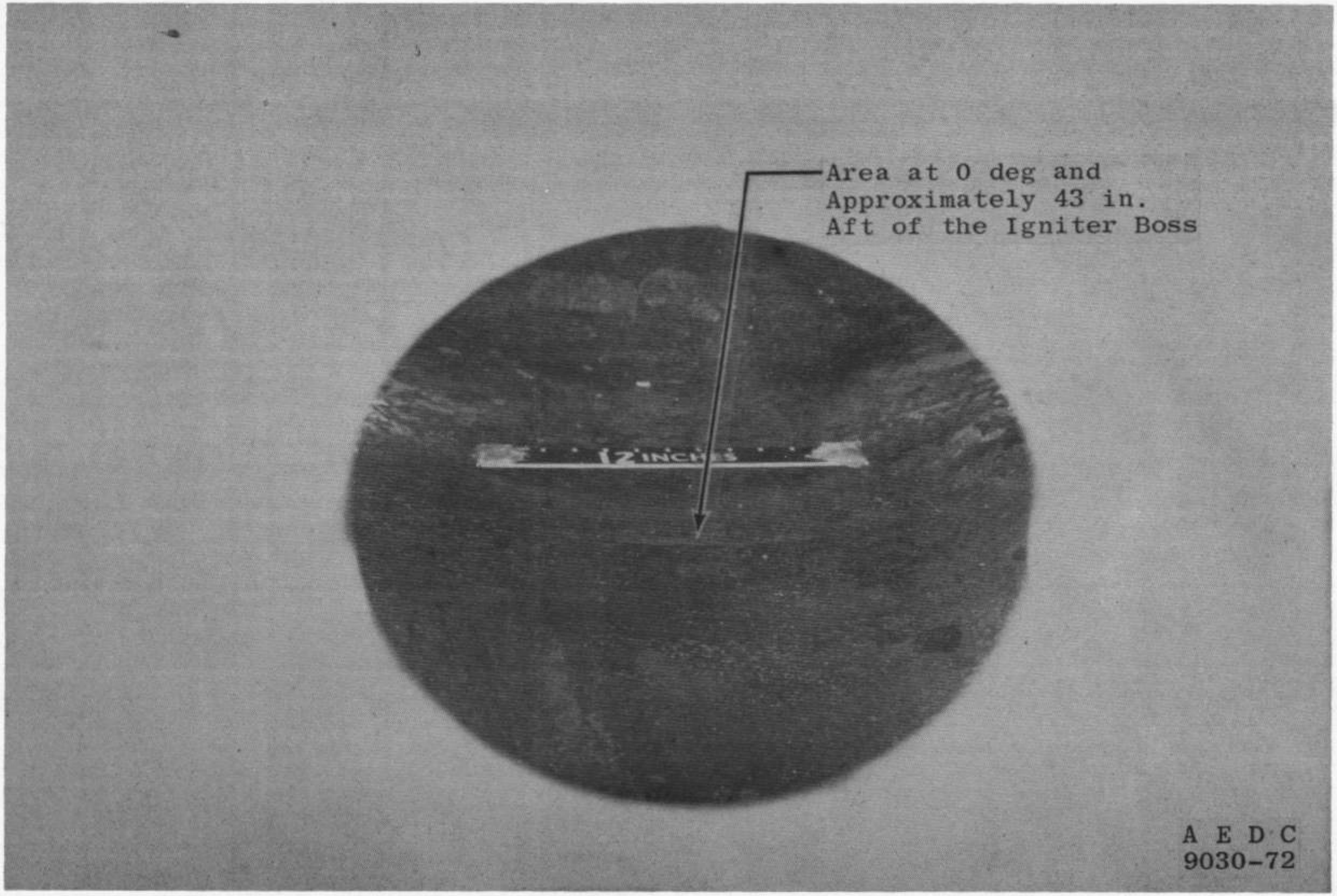
Notes: 1. Positions on forward dome located by arc dimensions from datum circle.
2. Linear positions on chamber located from datum plane.

Fig. 33 Motor Case Thermocouple Location



a. Overall View
Fig. 34 Test Article, Postfire

b. Motor Nozzle
Fig. 34 Continued



c. Internal Insulation Conditions
Fig. 34 Concluded

TABLE I
TEST ARTICLE INFORMATION SUMMARY

	Part No.	Serial No.	Vendor
Rocket Motor Assembly	382100-19	AA20078	AGC
Chamber and Support	382025-49	2192237	AGC-Downey
Chamber Insulated	383550-39	2192237	AGC
Chamber Assembly, Loaded	384744-9	2192237	AGC
Nozzle	384023-9	2168083	AGC-Downey
Nozzle Exit Cone	384517-19	2110260	Haveg-Reinhold
Motor Igniter	383617-79	2026311	AGC
Motor Igniter Safe/Arm	KR80000-07	OB-22112	Bulova
LITVC	1107481-57	AAB-0333	Space General
Gas Generator	4381000-1	CAA-1004	Olin Mathieson
TVC Igniter	1124136-1	BAH-0924	Olin Mathieson
Relief Valve	1111906	DAC-0038	Vickers, Inc.
Roll Control	1107506-23		Space General
Gas Generator	4361000-3	BAA-1184	Olin Mathieson
RC Igniter	1124136-1	BAH-0926	Olin Mathieson
Arm/Disarm Switch	7300-11	EAO-1965	Consolidated Controls
Pressure Transducers (CTLI)			
Motor Chamber	366480	4356	Statham
Freon Manifold	366557-3	4251	Statham
Roll Control Gas Generator	366557-1	3990	Statham
LITVC System Servoinjector Vavles (Model 50-275D)			
Position 1 (0°)	010-42964	104	MOOG, Inc.
Position 2 (90°)	010-42964	42	MOOG, Inc.
Position 4 (270°)	010-42964	110	MOOG, Inc.

TABLE II
SUMMARY OF MOTOR INSTRUMENTATION

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	ACCELERATION	G PEAK		G PEAK				
AIGN90Y	IGNITOR BOSS @ 90 D	-300 TO 300	PIEZOELECTRIC	1000 TO -1000		X		
	EVENT-VOLTAGE	V DC						
EFS-1	MAIN MOTOR IGNITION	0 TO 28			X	X	X	
EFS-2	MAIN MOTOR IGNITION	0 TO 28			X		X	
EFS-3	LITVC IGNITION	0 TO 28			X		X	
EFS-4	LITVC IGNITIUN	0 TO 28			X		X	
EFS-5	RCLL CONTROL IGNIT.	0 TO 28			X		X	
EFS-6	ROLL CONTROL IGNIT.	0 TO 28			X		X	
	EVENT	V DC						
ES-1	INJ. VALVE #1 COMM.	0 TO 3.5			X		X	
ES-2	INJ. VALVE #2 COMM.	0 TO 3.5			X		X	
ES-4	INJ. VALVE #4 COMM.	0 TO 10			X		X	
ERCV-1	RC COMMANC VOLTAGE	- 30 TO 30			X		X	
ERCV-2	RC COMMAND VOLTAGE	- 30 TO 30			X		X	
	FORCE	LBF		LBF				
FY-1	AXIAL THRUST	0 TO 80000	STRAIN GAGE	-100000 TO 100000	X		X	
FY-2	AXIAL THRUST	0 TO 80000	STRAIN GAGE	-100000 TO 100000	X			
FY-5	AXIAL THRUST	0 TO 80000	STRAIN GAGE	-100000 TO 100000		X		
FZA-1	AFT YAW	-6000 TO 6000	STRAIN GAGE	6000 TO -6000	X		X	
FZA-2	AFT YAW	-6000 TO 6000	STRAIN GAGE	6000 TO -6000	X			
FZA-3	AFT YAW	-6000 TO 6000	STRAIN GAGE	6000 TO -6000		X		
FZF-1	FORWARD YAW	-2000 TO 2000	STRAIN GAGE	6000 TO -6000	X		X	
FZF-2	FORWARD YAW	-2000 TO 2000	STRAIN GAGE	6000 TO -6000	X			
FZF-3	FORWARD YAW	-2000 TO 2000	STRAIN GAGE	6000 TO -6000		X		
	EVENT-CURRENT	AMP						
IFS-1	MAIN MOTOR IGNITION	0 TO 10			X	X	X	
IFS-2	MAIN MOTOR IGNITION	0 TO 10			X		X	
IFS-3	LITVC IGNITION	0 TO 10			X		X	
IFS-4	LITVC IGNITIUN	0 TO 10			X		X	
IFS-5	ROLL CONTROL IGNIT.	0 TO 10			X		X	

TABLE II (Continued)

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	EVENT-CURRENT	AMP						
IFS-6	ROLL CONTROL IGNIT.	0 TO 10			X		X	
IRCV-1	RC VALVE #1 COMMAND	0 TO 2.0			X		X	
IRCV-2	RC VALVE #2 COMMAND	0 TO 2.0			X		X	
	POSITION	MILS		MILS				
LINJ-1	PINTLE VALVE #1	0 TO 190	LVDT	0 TO 300	X		X	
LINJ-2	PINTLE VALVE #2	0 TO 190	LVDT	0 TO 300	X		X	
LINJ-4	PINTLE VALVE #4	0 TO 300	LVDT	0 TO 300	X		X	
LRCV-1	ROLL CONTROL VALVE 1	0 TO 6 V DC	LVDT	0 TO 6 V DC	X		X	
LRCV-2	ROLL CONTROL VALVE 2	0 TO 6 V DC	LVDT	0 TO 6 V DC	X		X	
	PRESSURE	PSIA		PSIA				
PA-1	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X		X	
PA-2	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X	X		
PA-5	TEST CELL	0 TO 15	STRAIN GAGE	0 TO 15	X			
PC-1	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 750	X		X	
PC-2	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 750	X	X	X	
PHC	HYDRAULIC SUPPLY	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PINJ-1	INJECTOR VALVE #1	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PINJ-2	INJECTOR VALVE #2	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PINJ-4	INJECTOR VALVE #4	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PMF-4	FREON MANIFOLD	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PRCGG	ROLL CONTROL GAS GEN	0 TO 2500	STRAIN GAGE	0 TO 2500	X		X	
PRCNI-1	ROLL CONTROL NOZ. #1	-500 TO 500	STRAIN GAGE	2000 TO -2000	X		X	
PRCNI-2	ROLL CONTROL NOZ. #2	-500 TO 500	STRAIN GAGE	300 TO -300	X		X	
PT-1	FREON TANK	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PTVCGG	TVC GAS GENERATOR	0 TO 1500	STRAIN GAGE	0 TO 1500	X		X	
	TEMPERATURE	DEG. F		DEG. F				
TA-1	AMBIENT TEST CELL	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TA-2	AMBIENT TEST CELL	0 TO 350	C/A, TYPE K	-300 TO 2500	X			
TCC-8	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCC-10	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCC-12	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCC-14	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCC-16	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCC-18	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCC-32	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCC-33	COMB CHAMBER SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCF-1	FORWARD DOME SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCF-3	FORWARD DOME SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			

TABLE II (Concluded)

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	TEMPERATURE	DEG. F		DEG. F				
TCF-4	FORWARD CONE SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TCF-6	FORWARD CONE SURFACE	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TMF-1	FREON MANIFOLD	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TMF-2	FREON MANIFOLD	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TMF-4	FREON MANIFOLD	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TRCGG	ROLL CONTROL GAS GEN	0 TO 1000	C/A, TYPE K	-300 TO 2500	X			

TABLE III
NOZZLE INSPECTION SUMMARY

Prefire Nozzle Throat and Exit Diameters

Plane, deg.	Throat Diameter, in.	Exit Diameter, in.
0	9.633*	47.810
30	–	47.808
60	9.633*	47.795
90	–	47.815
120	9.633*	47,790
150	–	47.790
Average	9.633	47.8013
Area, sq in.	72.881	1794.61

Postfire Nozzle Throat and Exit Diameters

Plane, deg.	Throat Diameter, in.	Exit Diameter, in.
0	9.560	47.660
30	9.559	47.570
60	9.565	47.575
90	9.557	47.610
120	9.608	47.690
150	9.578	47.570
Average, in.	9.5712	47.6125
Area, sq in.	71.948	1780.46
Percent Change in Area	–1.28	–0.79

*Supplied by ASPC

TABLE IV
MOTOR TEMPERATURE-CONDITIONING LOG

Date	Temperature, °F		Location of Motor	Relative Humidity, percent		Remarks
	High	Low		High	Low	
11/6/72	72	72	X-ray	30	25	Unloaded at X-ray at 1000 hr
11/7/72	72	70		34	26	
11/8/72	72	66		31	24	
11/9/72	73	70		30	21	
11/10/72	72	71		36	30	
11/11/72	71	70		36	30	
11/12/72	72	70		32	28	
11/13/72	72	70	X-ray	36	32	Moved to Rocket Preparation Area at 0840 hr; exposed to 62°F for 35 min
11/13/72	70	69	Rocket Preparation Area	65	56	
11/14/72	71	68		63	32	
11/15/72	68	66		46	29	
11/16/72	66	67		34	29	
11/17/72	68	67		34	24	
11/18/72	66	67		42	22	
11/19/72	66	66		54	42	
11/20/72	68	66		44	37	
11/21/72	76	66		37	22	
11/22/72	76	66		31	21	
11/23/72	67	66		30	21	
11/24/72	67	66		25	17	
11/25/72	67	66		45	25	
11/26/72	68	67		41	26	
11/27/72	67	66		45	28	
11/28/72	67	66		54	36	
11/29/72	67	66		44	32	
11/30/72	66	66		43	32	
12/1/72	66	66		32	30	
12/2/72	67	66		32	27	
12/3/72	68	65		53	30	
12/4/72	66	65		62	53	
12/5/72	65	64		68	62	
12/6/72	68	64		66	22	
12/7/72	66	65		36	21	
12/8/72	65	64		63	36	
12/9/72	65	64		66	59	
12/10/72	70	65		68	36	
12/11/72	66	64	Rocket Preparation Area	42	32	Moved to test cell at 0200 hr; exposed to 40°F for 2 hr
12/11/72	67	65	Test Cell	49	36	
12/12/72	66	65		72	49	Test cell evacuated to altitude conditions at 1435 hr; motor fired at 1600 hr

TABLE V
SUMMARY OF MOTOR PERFORMANCE

	ACTUAL	SPECIFICATION LIMITS MINIMUM	MAXIMUM	PREDICTED AT 80 DEG F. *
GENERAL INFORMATION				
MOTOR S/N	AA20078			
MOTOR DESIGNATION	OP-15			
MODEL NUMBER	SR19-AJ-1			
DATE FIRED	12-12-72			
DATE CAST	08-26-65			
CURE DATE	09-07-65			
GROSS MOTOR WEIGHT, LBM *	15504.7		15598	
MANUFACTURER'S STATED PROPELLANT WEIGHT, LBM *	13745.9	13680		
USEFUL PROPELLANT WEIGHT, LBM	13740.9			
SYSTEM MASS FRACTION *	0.886	0.884		
PREFIRE NOZZLE THROAT AREA, SQ. IN.	72.881			
AVERAGE NOZZLE THROAT AREA, SQ. IN.	73.431			
PREFIRE NOZZLE EXIT AREA, SQ. IN.	1794.61			
PREFIRE PROPELLANT BULK TEMPERATURE, DEG F.	66			
MOTOR PREFIRE CENTER OF GRAVITY *				
AFT OF FORWARD SKIRT, IN.	55.337	53.2	56.8	
RADIAL FROM MOTOR LONGITUDINAL CENTERLINE, IN.	0.047		0.150	
X AXIS	116.127			
Y AXIS	100.045			
Z AXIS	99.985			
ALTITUDE				
GAS GENERATOR IGNITION, FT.	106000			
MAIN MOTOR IGNITION, FT.	98000			
AVERAGE DURING ACTION TIME, FT.	100000			
BALLISTIC PERFORMANCE				
FORCE				
MAXIMUM MEASURED AXIAL				
AT FIRING TEMPERATURE, LBF	69493			
ADJUSTED TO 80 DEG. F., LBF	70472			
MAXIMUM UNAUGMENTED VACUUM AXIAL				
AT FIRING TEMPERATURE, LBF	69805			
ADJUSTED TO 80 DEG. F., LBF	70789			
AVERAGE MEASURED AXIAL DURING ACTION TIME				
AT FIRING TEMPERATURE, LBF	59882			
ADJUSTED TO 80 DEG. F., LBF	60726			
AVERAGE UNAUGMENTED VACUUM AXIAL DURING ACTION TIME				
AT FIRING TEMPERATURE, LBF	60042	53900	64000	
ADJUSTED TO 80 DEG. F., LBF	60888	54600	64800	60966
IMPULSE				
MEASURED TOTAL DURING ACTION TIME				
INCLUDING THRUST AUGMENTATION, LBF-SEC.	3941444			
VACUUM TOTAL DURING ACTION TIME				
INCLUDING THRUST AUGMENTATION	3959942			
EXCLUDING THRUST AUGMENTATION	3951955	3907000		3950572
SPECIFIC DURING ACTION TIME				
STANDARD (SISP10), LBF-SEC./LBM	249.72			
VACUUM EXCLUDING THRUST AUGMENTATION, LBF-SEC./LBM	287.61			287.4
MEASURED, LBF-SEC./LBM	286.84			
PERCENT OF VACUUM TOTAL DIRECTLY MEASURED	99.53			

TABLE V (Continued)

	ACTUAL	SPECIFICATION LIMITS MINIMUM	SPECIFICATION LIMITS MAXIMUM	PREDICTED AT 80 DEG F. *
PRESSURE				
MAXIMUM CHAMBER DURING IGNITION TRANSIENT, PSIA	452		570	
MAXIMUM NOZZLE STAGNATION DURING IGNITION TRANSIENT, PSIA	409			
MAXIMUM CHAMBER RISE RATE, PSIA/SEC.	7942			
AVERAGE CHAMBER DURING ACTION TIME				
AT FIRING TEMPERATURE, PSIA	456			
ADJUSTED TO 80 DEG. F., PSIA	462			
AVERAGE NOZZLE STAGNATION DURING ACTION TIME				
AT FIRING TEMPERATURE, PSIA	454			
ADJUSTED TO 80 DEG. F., PSIA	460			462
MAXIMUM CHAMBER				
AT FIRING TEMPERATURE, PSIA	530		570	
ADJUSTED TO 80 DEG. F., PSIA	538			544
CHAMBER INTEGRAL DURING ACTION TIME, PSIA-SEC.	29997			
NOZZLE STAGNATION INTEGRAL DURING ACTION TIME, PSIA-SEC.	29878			
TIME				
ACTION				
AT FIRING TEMPERATURE, SEC.(TA)	65.82			
ADJUSTED TO 80 DEG. F., SEC.	64.90			64.8
IGNITION DELAY, MSEC. (TO PC=371 PSIA)	109		250	
AT MAXIMUM CHAMBER PRESSURE, SEC.	21.10			
VACUUM THRUST DECAY FROM 41000 TO 2000 LBF AT 80 DEG. F., SEC.	2.05			
AVERAGE UNAUGMENTED VACUUM THRUST COEFFICIENT	1.802			
AVERAGE MEASURED THRUST COEFFICIENT	1.797			
MISCELLANEOUS				
MASS FLOW COEFFICIENT	0.006265			
CHARACTERISTIC EXHAUST VELOCITY, FT/SEC.	5137			
LIQUID INJECTION THRUST VECTOR CONTROL SYSTEM PERFORMANCE				
FORCE				
AVERAGE RESULTANT YAW DURING FULL-OPEN COMMAND FROM 2 TO 3 SEC., LBF	4406	3800		
MAXIMUM YAW 0.250 TO 3.0 SEC., LBF	4554			
MINIMUM YAW 2 TO 3 SEC., LBF	4275			
AVERAGE RESULTANT YAW DURING COMMAND FROM 52 TO 53 SEC., LBF	2261			
PRESSURE				
AVERAGE MAXIMUM OF THREE INJECTOR CAVITIES AND FREON MANIFOLD				
FROM TGG + 0.88 TO TGG + 6.4 SEC., PSIA	642		713	
FROM TGG + 6.4 TO TA, SEC., PSIA	629		680	
AVERAGE MINIMUM OF THREE INJECTOR CAVITIES AND FREON MANIFOLD				
FROM TGG + 0.88 TO TGG + 6.4 SEC., PSIA	556			
FROM TGG + 6.4 TO TA, SEC., PSIA	553			
MINIMUM INJECTOR CAVITY AT FULL FLOW, PSIA	533			

TABLE V (Concluded)

	ACTUAL	SPECIFICATION LIMITS MINIMUM	SPECIFICATION LIMITS MAXIMUM	PREDICTED AT 80 DEG F. *
INJECTOR CAVITY AT 71.8, SEC.				
INJECTOR 1, PSIA	577			
INJECTOR 2, PSIA	581			
INJECTOR 4, PSIA	581			
FREON MANIFOLD, PSIA	581			
MAXIMUM AT AN INJECTOR AFTER TGG + 0.88 SEC., PSIA	649			
MINIMUM AT AN INJECTOR AFTER TGG + 0.88 SEC., PSIA	533			
AVERAGE MAXIMUM INJECTOR PRESSURE AT NO FLOW, PSIA	643			
AVERAGE MINIMUM INJECTOR PRESSURE AT NO FLOW, PSIA	581			
MAXIMUM AT FREON MANIFOLD AFTER TGG + 0.88 SEC., PSIA	638			
TIME				
FROM TGG IGNITION UNTIL FIRST INDICATION OF PRESSURE IN EACH INJECTOR				
INJECTOR 1, MSEC.	160		880	
INJECTOR 2, MSEC.	135		880	
INJECTOR 4, MSEC.	140		880	
FROM TGG IGNITION UNTIL 500 PSIA FREON TANK PRESSURE, MSEC.	320		950	
FROM TGG IGNITION UNTIL MAXIMUM PRESSURE AT AN INJECTOR, SEC.	1.06			
FROM TGG IGNITION UNTIL MINIMUM PRESSURE AT AN INJECTOR, SEC.	5.93			
FROM TGG IGNITION UNTIL MAXIMUM FREON MANIFOLD PRESSURE, SEC.	1.29			
FROM TGG IGNITION UNTIL 500 PSIA IN LAST INJECTOR CAVITY, MSEC.	320			
OF MAXIMUM YAW FORCE FROM 0.250 TO 3.0 SEC.	2.77			
RESULTANT THRUST VECTOR ANGLE FROM 52 TO 53 SEC., DEG.	2.30	2.00		
TOTAL INJECTANT PROGRAMMED AND EXPENDED TO 72 SEC., LBM	172			
TOTAL INJECTANT EXPENDED UNTIL FREON SUPPY DEPLETED, LBM	210			
MAXIMUM THRUST VECTOR ANGLE FROM 52 TO 53 SEC., DEG.	2.58			
ROLL CONTROL SYSTEM PERFORMANCE				
PRESSURE				
MAXIMUM ROLL CONTROL GAS GENERATOR, PSIA	2098			
MINIMUM ROLL CONTROL GAS GENERATOR FROM TGG + 3.7 TO TGG + 8.2 SEC.	1519			
MAXIMUM ROLL CONTROL GAS GENERATOR FROM TGG + 3.7 TO TGG + 10.2 SEC.	1737			
AT TGG + 10.2 SEC.	755			
AT TGG + 28.0 SEC.	386			
AT TGG + 60.0 SEC.	326			
AT TGG + 75.0 SEC.	322			
TIME				
ROLL CONTROL VALVE RESPONSE				
NULL TO 90 PERCENT HARDOVER, MSEC.	16		35	
HARDOVER TO 10 PERCENT NULL, MSEC.	17		50	
HARDOVER TO 90 PERCENT HARDOVER, MSEC.	18		50	
FROM TGG UNTIL 1560 PSIA IN ROLL CONTROL GAS GENERATOR, MSEC.	200		720	
FROM TGG IGNITION UNTIL MAXIMUM ROLL CONTROL GAS GENERATOR PRESSURE, SEC.	0.81			
FROM TGG IGNITION UNTIL MINIMUM PRCGG FROM TGG+3.7 TO TGG+8.2 SEC., SEC	7.55			
FROM TGG IGNITION UNTIL MAXIMUM PRCGG FROM TGG+3.7 TO TGG+10.2 SEC., SEC.	3.70			
GAS GENERATOR BURN DURATION, SEC.	96.40			
TORQUE				
CAPACITY AT TGG+7.7 SEC.	418			
CAPACITY AT TGG+15.7 SEC.	142			
CAPACITY AT TGG+72.4 SEC.	89			

* FROM MOTOR LOG BOOK

TABLE VI
BALLISTIC PERFORMANCE SUMMARY OF LGM-30F STAGE II MOTORS FIRED AT AEDC

Motor	AEDC TR Number	Date Fired	Motor Age, yr	Prop. Temp., °F	Ign. Delay, msec	TA, sec	Average FVAC, lbf	Average PC, psia	Average CFVAC	Average Alt., ft	IV, lbf-sec	ISPV, lbf-sec/lbm
QUALIFICATION												
52QT-2	65-43	November 1964	0.9	75	134	63.6	61,900	470	1.81*	96,000	3,937,400	286.9
52QT-6	65-44	November 1964	0.8	64	114	64.2	61,820	465	1.82*	98,000	3,939,100	287.1
52QT-10	65-85	January 1965	0.5	66	118	68.1	58,000	442	1.80*	96,000	3,949,600	287.7
52QT-9	65-120	March 1965	0.8	73	125	71.2	55,460	422	1.80*	98,000	3,942,800	287.0
52QT-12	65 182	June 1965	0.9	70	144	69.1	57,260	438	1.80*	97,000	3,955,800	286.9
52QT-4A	65-219	July 1965	1.4	76	110	66.2	59,950	451	1.82*	95,000	3,968,000	289.2
OPERATIONAL A & S												
OP-1	68-156	March 1968	3.1	83	130	68.7	57,600	437	1.82*	94,000	3,955,800	287.4
OP-2	69 70	November 1968	3.9	67	220	69.64	56,800	424	1.84*	99,000	3,954,800	287.9
OP-3	69-72	November 1968	3.6	65	155	67.79	58,300	445	1.81*	102,000	3,954,000	287.3
OP-4	69-243	June 1969	4.3	72	135	69.47	57,000	432	1.82*	91,000	3,959,400	287.7
OP-6	70-222	April 1970	5.3	69	120	68.92	57,420	436	1.81*	101,000	3,957,700	288.0
OP-7	70-240	August 1970	5.5	65	126	69.85	56,790	431	1.79**	99,000	3,955,500	287.9
OP-8	71-44	December 1970	5.8	64	150	69.53	56,830	432	1.80**	101,000	3,951,300	287.1
OP-5	71-104	March 1971	6.0	67	138	70.80	55,820	424	1.79**	101,000	3,952,300	287.5
OP-9	71-189	June 1971	6.2	88	127	68.26	57,850	441	1.80**	99,000	3,948,700	287.6
OP-10	71-250	October 1971	6.5	63	114	69.53	56,810	432	1.80**	98,000	3,950,013	287.4
OP-11	71-266	October 1971	6.7	66	103	69.72	56,741	431	1.80**	99,000	3,955,979	287.64
OP-12	72-58	February 1972	7.0	66	253	67.77	58,399	443	1.81**	98,000	3,957,678	287.42
OP-13	72-120	July 1972	7.3	64	106	70.00	56,433	431	1.78**	99,000	3,950,319	287.16
OP-14	72-166	September 1972	7.3	67	102	69.48	56,925	433	1.80**	98,000	3,955,139	287.72
OP-15	73-30	December 1972	7.3	66	109	85.82	60,042	456	1.80**	100,000	3,951,955	287.81
STORAGE A & S												
52MS-12	68-153	March 1968	3.6	64	222	71.49	55,260	421	1.81*	88,000	3,950,200	287.5
52MS-11	69-46	November 1968	4.3	63	245	69.63	56,670	432	1.81*	103,000	3,947,000	287.5
52MS-10	69-120	March 1969	4.6	66	185	70.82	55,710	422	1.82*	108,000	3,947,600	287.3
52MS-9	70-59	October 1969	5.1	67	138	71.97	55,030	417	1.81*	99,000	3,955,100	287.8
52MS-8	70-98	December 1969	5.5	68	126	69.80	58,210	429	1.80*	102,000	3,923,600	285.7
52MS-7	70-245	May 1970	6.0	68	120	68.42	57,720	438	1.81*	102,000	3,949,300	287.3
52MS-6	71-182	June 1971	7.0	67	222	69.17	56,960	432	1.81**	107,000	3,939,900	287.4
52MS-5	72-75	April 1972	7.9	87	139	69.79	58,532	429	1.80**	98,000	3,945,383	287.52

*Calculated using prefire throat area
**Calculated using a varying throat area

TABLE VII
ROLL CONTROL DUTY CYCLE

Time, sec*	Command	Frequency, Hz
0 - 2	Hardover CCW	-
2 - 3	Null	-
3 - 4	Hardover to Hardover	10
4 - 5	Null	-
5 - 6	Null to Hardover CCW	10
6 - 7	Null	-
7 - 8	Null to Hardover CW	10
8 - 10	Hardover CCW	-
10 - 11	Hardover to Hardover	10
11 - 12	Null	-
12 - 15	Null to Hardover CW	10
15 - 18	Null to Hardover CCW	10
18 - 21	Hardover to Hardover	10
21 - 24	Null	-
24 - 27	Hardover CCW	-
27 - 30	Null to Hardover CCW	10
30 - 33	Null to Hardover CW	10
33 - 36	Hardover to Hardover	10
36 - 39	Null	-
39 - 42	Hardover CW	-
42 - 45	Null to Hardover CW	10
45 - 48	Null to Hardover CCW	10
48 - 51	Hardover to Hardover	10
51 - 54	Null	-
54 - 57	Hardover CCW	-
57 - 60	Null to Hardover CCW	10
60 - 63	Null to Hardover CW	10
63 - 66	Hardover to Hardover	10
66 - 69	Null	-
69 - 72	Hardover CW	-
72 - 75	Null to Hardover CW	10
75 - 78	Null to Hardover CCW	10
78 - 81	Hardover to Hardover	10
81 - 84	Null	-
84 - 87	Hardover CCW	-
87 - 120	Null	-

* Time is referenced to motor ignition (T). Gas generator is ignited at T-3.7 sec.

TABLE VIII
THRUST VECTOR CONTROL DUTY CYCLE

Time, sec*	Injector 1	Injector 2	Injector 4
0-2	0	0	0
2-3	0	0	Full Open
3-5	0	0	0
5-8	0	0-10 lb/sec Ramp	0
8-9	0	10 lb/sec	0
9-12	0	0	0
12-15	±1 lb/sec at 1 cps**	0	±1 lb/sec at 1 cps**
15-16	0	0	0
16-20	1 lb/sec	0	1 lb/sec
20-23	0	0	0
23-27	0	±1 lb/sec at 3 cps**	
27-28	0	0	0
28-31	0	1 lb/sec	0
31-32	0	0	0
32-34	±1 lb/sec at 7 cps**	0	±1 lb/sec at 7 cps**
34-51	0	0	0
51-52	0	0	0-28 lb/sec Ramp
52-53	0	0	28 lb/sec
53-58	0	0	0
58-59	0	0	0-20 lb/sec Ramp
59-60	0	0	0
60-72	0	1.25 lb/sec	0
72-99	0	0	0
100-120	10 lb/sec	0	0

* Time is referenced to motor ignition.

** ±1 lb/sec sinusoidal wave about a 1 lb/sec constant bias.

TABLE IX
LIQUID-INJECTION THRUST VECTOR CONTROL PERFORMANCE SUMMARY

LIQUID INJECTION THRUST VECTOR CONTROL PERFORMANCE SUMMARY

NOMINAL TIME, SEC	2-3	8-9	16-20*	28-31*	52-53
START TIME (CALC)	2.370	8.230	16.320	28.240	52.250
STOP TIME (CALC)	2.910	8.910	19.910	30.910	52.910
INJECTOR NUMBER	4	2	4	2	4
SPECIFIED FLOW RATE, LBM/SEC.	FULL OPEN	10.0	1.0	1.0	28.0
ACTUAL FLOW RATE, LBM/SEC.	58.0	9.73	1.35	1.26	26.8
PINTLE POSITION, MILLIINCHES	277.22	92.68	11.04	10.11	191.40
PINTLE PRESSURE, PSIA	545.	598.	598.	600.	571.
PROPELLANT FLOW RATE, LBM/SEC.	189	226	241	234	196
INJECTOR-TO-PROPELLANT FLOW RATE RATIO	0.307	0.043	0.006	0.005	0.137
RESULTANT YAW FORCE, LBF	4406.	1161.	249.6	197.8	2261.
UNAUGMENTED VACUUM AXIAL THRUST, LBF	54507	64991	69327	67270	56225
YAW-TO-AXIAL FORCE RATIO	0.0808	0.0179	0.0036	0.0029	0.0402
JET DEFLECTION ANGLE, DEG.	4.62	1.02	0.21	0.17	2.30
RESULTANT YAW FORCE INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	76	119	185	157	84
AXIAL-THRUST AUGMENTATION, LBF	2102.	530.0	180.9	51.8	1089.
PERCENT AXIAL-THRUST AUGMENTATION	3.86	0.82	0.26	0.08	1.94
AXIAL-THRUST AUGMENTATION INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	36.3	54.5	**	**	40.7

* DURING THIS TIME PERIOD, BOTH PITCH AND YAW INJECTORS WERE OPERATING. IT WAS ASSUMED THAT EFFECTS OF SIMULTANEOUS INJECTION IN THE PITCH AND YAW PLANES WERE INDEPENDENT.

** DATA NOT PRESENTED FOR LOW FLOW STEPS.

TABLE X
SUMMARY OF MOTOR THERMAL DATA

Sidewall Thermocouples	Motors 52 QT 7., 8, -9, ΔT, °F(avg)	Motors 52 QT -10, -11, -12, ΔT, °F Range	Temperature Increase During Action Time, °F Motors 52MS 12	-11	-10	-9	-8	-7	-6	-5
TCC-120-101 5	10	3 to 14	**	11	10	8	10	10	8	8
TCC-180-101 5	9	8 to 12	11	12	11	12	10	5	8	8
TCC-120-93 5	12	8 to 16	16	11	14	9	10	12	10	13
TCC-180-93 5	11	8 to 15	18	11	4	8	13	18	12	7
TCC-120-89.5	8	7 to 13	10	7	9	7	8	4	8	8
TCC-180-89.5	8	6 to 11	11	5	10	10	10	10	8	8
TCC-120-59 5	2	0 to 5	7	4	2	4	14	3	2	**
TCC-180-59.5	3	1 to 5	8	2	1	3	8	2	2	2
TCC-120-45.0	3	2 to 6	10	**	2	3	3	5	2	3
TCC-180-45 0	2	0 to 4	7	0	2	3	3	2	2	3
TCC-120-33 0	2	1 to 4	15	**	5	2	2	4	3	5
TCC-180-33 0	2	2 to 4	7	1	5	2	3	4	5	5
TCC-0-31.0	3	2 to 8	4	0	3	2	2	**	**	5
TCC-270-31 0	3	2 to 4	9	1	5	2	6	5	2	7
TCC-0-28.0	3	2 to 4	2	0	2	**	3	1	**	0
TCC-90-28.0	3	2 to 8	10	2	2	3	4	3	6	0
TCC-80-31 0	2	1 to 3	22	0	6	1	4	9	3	7
TCC-270-28.0	3	1 to 5	6	1	4	1	5	2	2	5
TCC-120 21 0	3	0 to 7	4	0	2	2	3	3	2	3
TCC-180 21 0	3	0 to 6	**	1	2	2	2	3	2	2
TCC-120-15.0	3	0 to 6	1	0	2	3	2	2	2	2
TCC-180-15 0	3	0 to 6	**	1	2	2	2	2	2	2
Forward Closure Thermocouples										
TCF-120-6 0	61	44 to 78	79	61	90	60	58	32	49	72
TCF-180-6 0	53	48 to 86	70	48	80	64	64	26	52	57
TCF-120-12 0	38	23 to 56	74	76	84	59	55	20	42	45
TCF-180-12 0	49	40 to 62	77	58	92	81	66	24	48	58
TCF-120-18 0	35	30 to 45	48	48	46	44	44	25	32	34
TCF-180-18 0	40	35 to 48	48	38	53	39	64	20	32	39
Aft Closure Thermocouples										
TCA-150-11.5	28	20 to 36	34	27	38	34	25	33	32	24
TCA-192-11.5	34	31 to 40	**	28	34	29	22	37	30	25
TCA-210-11 5	34	20 to 42	43	26	34	29	28	33	29	23
TCA-150-7 2	32	31 to 36	60	27	42	39	33	28	39	34
TCA-180-7.2	35	30 to 45	48	28	48	37	33	38	33	32
TCA-210-7.2	38	30 to 51	**	33	42	35	38	28	35	30
TCA-150-3 0	30	23 to 38	**	30	49	35	28	22	35	25
TCA-180-3.0	31	20 to 40	45	28	47	33	31	52	28	29
TCA-210-3 0	34	27 to 40	42	28	37	29	34	24	28	28

** Invalid

*** Not installed

TABLE X (Concluded)

Sidewall Thermocouples	Motors OP -1	-2	-3	-4	-6	-7	-8	-5	-9	-10	-11	-12	-13	-14	-15
TCC-120-101.5	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-180-101.5	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-120-93.5	7	0	3	0	3	3	5	15	2	1	0	0	2	2	0
TCC-180-93.5	5	4	0	2	4	**	5	8	3	4	0	0	2	1	0
TCC-120-89.5	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-180-89.5	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-120-59.5	3	0	0	0	5	4	2	12	0	0	0	0	0	0	2
TCC-180-59.5	7	5	0	0	0	**	3	8	0	0	0	0	0	0	0
TCC-120-45.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-180-45.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-120-33.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-180-33.0	9	2	0	1	2	5	5	6	0	2	1	0	0	0	0
TCC-0-31.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-270-31.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-0-28.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-90-28.0	0	3	0	0	1	5	9	12	1	0	5	0	0	2	2
TCC-90-31.0	4	0	0	0	3	5	9	13	0	0	2	0	0	0	0
TCC-270-28.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-120-21.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-180-21.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-120-15.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCC-180-15.0	7	2	0	0	3	6	7	12	0	0	0	0	0	0	0
Forward Closure Thermocouples															
TCF-120-6.0	***	***	***	***	***	***	13	25	10	30	5	9	3	25	6
TCF-180-6.0	23	20	23	29	24	27	8	22	12	19	10	4	5	23	17
TCF-120-12.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCF-180-12.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCF-120-18.0	10	**	7	28	11	13	7	23	6	20	12	5	2	13	6
TCF-180-18.0	***	***	***	***	***	***	9	20	15	14	8	6	2	15	6
Aft Closure Thermocouples															
TCA-150-11.5	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCA-192-11.5	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCA-210-11.5	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCA-150-7.2	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCA-180-7.2	65	27	***	28	16	***	***	***	***	***	***	***	***	***	***
TCA-210-7.2	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCA-150-3.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TCA-180-3.0	56	33	***	29	27	***	***	***	***	***	***	***	***	***	***
TCA-210-3.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

APPENDIX III
INSTRUMENTATION CALIBRATIONS

The axial-thrust load cell was laboratory calibrated versus a force transfer standard. These calibrations were verified to be within ±0.1 percent of the in-place deadweight calibrations in the range from 0 to 80,000 lbf. Axial-thrust data were reduced utilizing the deadweight calibrations.

Pressure transducers were calibrated in the standards laboratory using a deadweight pressure generator. Thermocouple wires were calibrated by the manufacturer with standards traceable to the National Bureau of Standards. The pressure and temperature instrumentation recording systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions using the resistance shunting technique for the pressures and the voltage substitution method for the temperatures. These calibrations were automatically selected from the control room. The various thermocouples were connected directly to the referenced temperature junction, and National Bureau of Standards standard thermocouple curves were the basis of the temperature data calibrations.

Calibrations of the liquid-injection thrust vector control injector valves were performed using the dial-indicator pintle tool to physically measure the pintle positions on each servoinjector valve at the programmed command steps. Feedback voltages from the injector valves were measured and plotted against pintle position. The feedback voltage versus pintle position data were used to determine the injectant flow rates for each valve at its programmed command steps.

The accelerometer was calibrated in the AEDC calibration laboratory using an eccentric mass vibrator before installation. The recording system was calibrated by the frequency/voltage substitution technique.

APPENDIX IV
UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS

1.0 INTRODUCTION

The rationale for the estimated instrument system uncertainties contained in Table IV-1 is provided in this appendix. The general approach taken in the analysis, the definition of terms, and the specific evaluation of each system are presented.

2.0 METHODOLOGY

The approach taken in this analysis follows the methodology established by the Interagency Chemical Rocket Propulsion Group[1]. A review of the basic concepts and terminology is given in the following paragraphs in order to provide a better understanding of individual evaluations of the J-5 instrument systems.

The uncertainty of a measurement is defined to be the maximum difference reasonably expected between a measured value and the true value. Measurement errors have two components: fixed errors and random errors. A random error results from variations between repeated measurements and is called the precision error. The statistic, s, is an estimate of the standard deviation of a population and is called the precision index. It is calculated to estimate the precision error. The precision index is

$$s = \sqrt{\frac{\sum_{i}^{N} (x_i - \bar{x})^2}{(N - 1)}} \tag{1}$$

where

- N is the number of measurements
- $\bar{x}$ is the average value of the measurement
- x_i is the individual measurement

The second component of a measurement error is the constant or systematic error and is known as the bias. Each measurement of repeated measurements has the same bias. Large known biases are eliminated by calibrating the instrument, i.e., comparing the instrument to a standard and obtaining a correction. Small known biases may or may not be accounted for, depending upon the significance of the bias and the difficulty of

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[1]Abernethy, R. B., Colbert, D. L., and Powell, B. D. "ICRPG Handbook for Estimating the Uncertainty in Measurement Made with Liquid Propellant Rocket Engine Systems." Performance Standardization Group, CPIA No. 180, April 30, 1969.

correcting for the bias. Unknown biases are not correctable. Generally, the estimate of the limit for a bias is based upon judgment and experience.

In order to establish a single number for expressing a reasonable limit for the error of a measurement, some combination of bias and precision is required. It is recognized that it is impossible to define a rigorous statistic because the bias is an upper limit based upon judgment. The uncertainty U is established as that single number for stating an error. The uncertainty is centered about the measurement and is defined as

$$U = \pm(B + t_{0.95} S) \tag{2}$$

where

B is the estimated bias limit

S is the precision index

t is the 95th-percentile point for the two-tailed students "t" distribution

The "t" value is a function of the number of degrees of freedom (d.f.). For 30 or more degrees of freedom, a t value of 2 is assumed.

The uncertainty is an arbitrary substitute for a statistical confidence interval and can best be interpreted as the largest error to be expected. The coverage of U is greater than 95 percent under reasonable assumptions of the distribution of the bias.

In general, the errors in a measurement process originate from a multitude of different sources. The uncertainty of a total measurement can be established by two approaches:

(a) Determining the elemental error sources in the process and appropriately combining the errors and

(b) Determining the error of the complete system by comparison with a standard.

Since the error of a measurement process is the result of elemental error sources, a methodology for combining elemental errors is required in order to arrive at the total uncertainty U.

The bias limit B in equation (2) is calculated as

$$B = \sqrt{b_1^2 + b_2^2 + b_3^2 \text{----} b_n^2} \tag{3}$$

where

b_n is the n elemental error source

The above approach is taken because it is unreasonable to assume the unknown bias limits b_n are cumulative.

The precision error S in equation (2) is

$$S = \sqrt{s_1^2 + S_2^2 + S_3^2 ----s_n^2} \quad (4)$$

where

s_n is the precision error in the n elemental source elemental source

The degress of freedom for S may be found by use of the Welch-Safterthwaite formula as follows:

$$d.f. = \frac{(s_1^2 + s_2^2 + s_3^2 ----s_n^2)^2}{\frac{s_1^4}{df_1} + \frac{s_2^4}{df_2} + \frac{s_3^4}{df_3} ---- \frac{s_n^4}{df_n}} \quad (5)$$

The establishment of the d.f. for S makes it possible to define the precision error of subsequent measurement processes or analyses.

The uncertainties of the J-5 instrument systems are tabulated in Table IV-1.

TABLE IV-1
ESTIMATED TOTAL UNCERTAINTY (±2 SIGMA LIMITS) OF INSTRUMENT SYSTEMS USED IN DETERMINING MOTOR PERFORMANCE

	Uncertainty, percent, full scale
Pressure Measurements[1]	± 0.44
Temperature Measurements (Thermocouples, C/A)	± 0.47
Axial-Force Measurements	± 0.13
Side-Force Measurements	± 0.45

[1]Uncertainty calculated for AEDC-supplied transducers only.

APPENDIX V
METHODS OF CALCULATION

1. FA = Average measured axial thrust including augmentation, lbf

FA = (FY-1 + FY-2)/2

where

FY-1 and FY-2 are measured axial force

2. FTSM = Average measured thrust smoothed

$$= [FA_{(i-4)} + 2FA_{(i-3)} + 3FA_{(i-2)} + 4FA_{(i-1)} + 5FA_{(i)} + 4FA_{(i+1)} + 3FA_{(i+2)} + 2FA_{(i+3)} + FA_{(i+4)}]\ 1/25$$

3. PO = Average measured chamber pressure at the forward dome, psia

PO = (PC-1 + PC-2)/2

where

PC-1 and PC-2 are measured chamber pressure. The operational pressure transducer (PC-1) data will not be used if it disagrees more than 0.5percent with the facility transducer (PC-2).

4. PALT = Average test cell pressure, psia

PALT = (PA-1 + PA-2)/2

where

PA-1 and PA-2 are measured cell pressure

5. PSN = Nozzle throat stagnation pressure, psia

PSN = PO(PSN/PO)

where

PSN/PO is an input table furnished by Aerojet-General Corporation

Time, sec	PSN/PO
0.0	0.8800
0.25	0.9130
0.50	0.9240
0.75	0.9340
1.00	0.9410
1.50	0.9530
2.00	0.9620
2.50	0.9685
3.00	0.9735
3.50	0.9773
4.00	0.9805
5.00	0.9844
6.00	0.9873
7.00	0.9897
8.00	0.9915
10.00	0.9940
12.00	0.9960
14.00	0.9974
16.00	0.9985
18.00	0.9990
22.00	1.0000
End of Test	1.0000

6. ATC = Calculated throat area

a. From T to PSN = 200 psia

AT = Prefire measured throat area

b. From PSN = 200 psia until initiation of motor tailoff (determined by engineering personnel) AT is calculated by an iteration method utilizing the following equations:

(1) FTSMUVAC = (KFVAC) (PSN) (AT) (CFVAC)

$$\text{(2) } AE/AT = \lambda \left(\frac{\gamma - 1}{2}\right)^{1/2} \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{PSN}{Pe}\right)^{1/\gamma} \left[1 - \left(\frac{Pe}{PSN}\right)^{\frac{\gamma-1}{\gamma}}\right]^{-1/2}$$

$$\text{(3) } CFVAC = \lambda \gamma^{1/2} \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{2\gamma}{\gamma - 1}\right)^{1/2} \left[1 - \left(\frac{Pe}{PSN}\right)^{\frac{\gamma-1}{\gamma}}\right]^{1/2} + \frac{Pe}{PSN} \left(\frac{AE}{AT}\right)$$

where

KFVAC = FTSMVAC/(PSN)(AT Prefire)(CFVAC) theoretically calculated after the first injection step

Pe = Exit pressure, psia

λ = Theoretical nozzle correction factor (calculated using AGC Computer Program)

γ = Ratio of specific heats
= 1.20

a. An initial guess for Pe is taken and substituted into equation 2 to obtain AE/AT

b. This value of AE/AT is substituted into equation 3 to obtain CFVAC

c. With these values, equation 1 is solved for AT (Reference: Aerojet-General Job 603.1)

c. From initiation of tailoff to end of action time, AT is considered constant at the last valid area calculated.

7. FTSMVAC = Smoothed augmented axial thrust corrected to vacuum conditions, lbf

FTSMVAC = FTSM + PALT(AE)

where

AE = Prefire nozzle exit area

8. WDOTP = Propellant mass flow rate, lbm/sec

WDOTP = K6(PSN)(ATC)

where

K6 = WP-5/$\int_{T}^{TA}$ PSN (ATC) dt

WP-5 = Manufacturer's stated propellant weight -5, lbm

= Useful propellant weight

T = Time at first indication of ignition voltage

TA = Motor action time

9. Delta FTSM = Thrust augmentation attributable to secondary injection

Thrust augmentation attributable to secondary fluid injection is calculated utilizing the vacuum corrected axial thrust to nozzle throat stagnation pressure ratio (FPRVAC), and the vacuum corrected axial thrust to pressure ratio excluding augmentation (FPRUVAC).

a. FPRVAC = FTSMVAC/PSN

FPRUVAC = FPRVAC, during periods of no injection

FPRUVAC = $X + M(t_i - t_1)$, $t_1 \leq t_i \leq t_2$, during injection periods

where

X = FPRVAC at the beginning of the injection step

M = Slope of the straight line between FPRVAC at the beginning of each injection step and FPRVAC at the end of each injection step.

t_i = Instantaneous time, sec

t_1 = Time at the beginning of each injection step, sec

t_2 = Time at the end of each injection step, sec

b. The unaugmented vacuum axial thrust (FTSMUVAC) is then calculated as follows:

FTSMUVAC = (PSN) · FPRUVAC

c. The augmentation attributable to secondary injection (Delta FTSM) is obtained by subtracting the unaugmented axial thrust from the augmented axial thrust:

Delta FTSM = FTSMVAC - FTSMUVAC

10. $\overline{\text{CFVAC}}$ = Vacuum thrust coefficient

$\overline{\text{CFVAC}}$ = FTSMUVAC/(PSN)(ATC)

11. TRC = Roll control torque, ft-lbf

$$TRC = C_1 (PRCGG)$$

where

C_1 = 0.2745 ft-lbf/psia
(supplied by Odgen Air Materiel Area)

PRCGG = Measured roll control gas generator pressure, psia

12. Temperature corrected performance data

$$\text{Time } (t_s) = \text{Time } (t_f)/K$$

$$\text{Thrust } (t_s) = (K) \text{ Thrust } (t_f)$$

$$\text{Pressure } (t_s) = (K) \text{ Pressure } (t_f)$$

where

$$K = e^{\pi p (t_s - t_f)}$$

$$\pi p = 0.0010$$

t_s = Standard propellant grain temperature (80°F)

t_f = Propellant grain temperature at ignition

13. SISP10 = Specific impulse at standard conditions (chamber pressure = 1000 psia, exhaust pressure = 14.7 psia, and optimum expansion with a 15-degree, half-angle nozzle), lbf-sec/lbm

$$SISP10 = \frac{ISP\ STD\ TH}{ISP\ VAC\ TH} (ISPVAC)$$

where

ISP STD TH = Standard theoretical specific impulse at desired conditions

= 252.79 lbf-sec/lbm (given condition)

ISP VAC = Measured specific impulse at vacuum conditions, lbf-sec/lbm

ISP VAC TH = Theoretical vacuum specific impulse for a given propellant and nozzle area ratio, lbf-sec/lbm (taken from following table furnished by Aerojet-General)

Nozzle Area Ratio, A_{exit}/A_{throat}	ISP VAC TH, lbf-sec/lbm
21.1735	287.66
21.4351	287.94
21.6983	288.22
21.9631	288.50
22.2255	288.78
22.4821	289.04
22.7401	289.31
22.9996	289.57
23.2605	289.82
23.5209	290.08
23.7732	290.33
24.0269	290.58
24.2819	290.81
24.5382	291.05
24.7959	291.30

14. CW = Mass flow coefficient

$$CW = \frac{\text{useful propellant weight}}{\int_{T}^{TA} PSN\ (ATC)\ dt}$$

15. C* = Characteristic exhaust velocity

$$C^* = \frac{\left(\int_{T}^{TA} PSN\ dt/TA\right)\left(\int_{T}^{TA} ATC\ dt/TA\right) g}{\text{useful propellant weight}/TA}$$

16. WDOT-I = Injectant flow rate

$$\text{WDOT-I} = \text{WDOT(CAL)} \sqrt{\frac{[SPG(TEST)]\ [\Delta P(TEST)]}{[SPG(CAL)]\ [\Delta P(CAL)]}}$$

where

WDOT(CAL) = Input table with WDOT(CAL) as a function of pintle position

SPG(TEST) = Specific gravity of Freon 114B2 at the test temperature

= 2.180 - 0.00147 (TF - 70)

TF = Freon temperature, °F

SPG(CAL) = Specific gravity of Freon 114B2 at 80°F and 600-psig injectant pressure = 2.165

ΔP CAL = 600 psid

ΔP TEST = (PINJ-I) - PNE

PINJ-I = Injectant pressure at each injector valve as measured during the firing

I = 1, 2, 3, and 4 designates the injector valve number

PNE = Input table with PNE as a function of WDOT(CAL) (furnished by Aerojet-General)

PNE versus WDOTCAL

$\dot{W}$ (lbm/sec)	PNE (psia)
0	9.5
5	15.3
10	20.8
15	26.2
20	31.3
25	35.8
30	39.3
35	40.9
40	41.3
60	41.7
80	42.1

17. ISPINJ = Yaw force injectant specific impulse

ISPINJ = |FZRC|/WDOTFZ

FZRC = Resultant yaw force

WDOTFZ = Injectant flow rate through valve 2 or 4

18.* FZRC/FTSMUVAC = Yaw to axial-force ratio

where

FTSMUVAC = Smoothed unaugmented vacuum axial thrust

19.* WDOTR = Injectant to motor flow rate ratio

WDOTR = WDOT-I/WDOTP

where

I = Valves 1, 2, 3, and 4 or a combination of these valves

20.* AISP = Axial-thrust augmentation injectant specific impulse

AISP = Delta FTSM/WDOT-I

*Not valid during periods of no injection

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13 ABSTRACT LGM-30F Stage II solid-propellant rocket motor, designated OP-15, was fired on December 12, 1972, in Rocket Development Test Cell (J-5), Engine Test Facility (ETF), in support of the operational phase of the Minuteman Aging and Surveillance test program. The objective of this test was to determine any degradation in performance or decrease in reliability that may have occurred as a result of 7.3 years of operational deployment. Motor ballistic performance was within specification. The motor was ignited at a pressure altitude of 98,000 ft. Motor ignition delay time was 109 msec. Motor action time was 65.82 sec, during which the motor produced an unaugmented vacuum total impulse of 3,951,955 lbf-sec. The unaugmented vacuum specific impulse was 287.61 lbf-sec/lbm. Average chamber pressure during motor action time was 456 psia. The liquid-injection thrust vector control and roll control systems operated satisfactorily throughout the firing. Postfire motor structural integrity was satisfactory. Data are presented showing the performance of this motor as compared to the performance of other LGM-30F Stage II motors tested at AEDC.

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5 thrust vector control						

1. Missiles -- Minuteman, Stage II

2 SPR motors -- aging

3 " " -- Performance

4 " " --

6

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